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An Essay
on the
Physiology of Mind

An Interpretation Based on Biological, Morphological, Physical and Chemical Considerations

BY

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This Essay is Reverentially
Inscribed to the Memory
of
JOSEPH LEIDY
to whom especially we owe our
Knowledge of the Behavior
of the
Rhizopoda

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FOREWORD

In this essay the writer has endeavored to present the basic facts of those reactions of the organism to the environment which under given conditions manifest the qualities which we speak of as "mind." As far as possible elemental truths have been sought in a consideration of the structure of the constituent substance of the organism, the living protoplasm. The physical peculiarities of the latter, its ceaseless chemical change, its simultaneous up-building and reduction, its reactions and its lack of reactions to the incident forces of the physical world, have, in turn, been called to the attention of the reader. Secondly, the behavior of simple unicellular forms of life has been compared with and in a measure correlated with the behavior of the individual cells of multicellular forms.

In due course, also, have been considered those peculiarities of structure of the living protoplasm which cause the arrest of certain, a very limited number, of the incident forces of the environment; protoplasm as a whole is "transparent" to and remains totally unaffected by an infinitude of forces active in the universe.

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In turn the writer has taken up the problems of the reception and transmission of the forms of energy which protoplasm is capable of receiving, the conversion of these incident forces into other forms, and the transmission and the release of energy by the protoplasm itself. Naturally, this discussion is preceded by a consideration of elementary responses to impacts, by a consideration of the differentiation in metazoa of special structures for the reception and transmission of the latter, and for the resulting expression in motion; and, finally, by a consideration of the elaboration and differentiation of these phenomena in the more complex metazoa.

At first the responses of the organism are very general in character. Soon, however, they become limited and special, and later acquire the character of being fixed, stereotyped, and invariable. Later still, owing to an increase —an increase which finally becomes vast— in the number of the integers concerned in transmission and owing to the preservation in these integers of certain primitive and undifferentiated properties, the responses lose this quality of fixation. They become capable of variation and acquire the quality of being more and more adaptable and adjustable to the impacts received; the responses become more

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and more the exact or, rather, the increasingly approximate equivalents of the impacts.

The recondite problems of consciousness now present themselves and its elemental phenomena first occupy our attention. Finally, the writer directs attention to some of the remarkable physical facts definitely known in regard to the responses of the organism, facts which possess a profound significance and which must profoundly influence our conceptions both of the structure of protoplasm and of the limitations which this structure imposes. Here appears the great question: "What and how much does our structure permit us to know?"

In conclusion the writer wishes to say for the lay reader into whose hands this essay may fall, that as far as practicable the language employed has been as simple as the nature of the subject permits. Unfortunately, however, many technicalities are unavoidable, though, whenever possible, the meaning of these has been indicated in the text.

F. X. D.

1719 Walnut Street,
Philadelphia, Pa.
January, 1922.

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AN ESSAY

ON THE

PHYSIOLOGY OF MIND

An Interpretation Based on Biological, Morphological, Physical, and Chemical Considerations

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To the writer it has seemed that all of the phenomena embraced by human experience, no matter what their character, must be approached from the standpoint of cold, unemotional, scientific observation and analysis. This necessitates as a preliminary an attitude of mind in which preconceived ideas, prejudices of whatsoever character, previous beliefs, and conceptions are set aside. In no field is this more important that in the study of the phenomena embraced under the term "mind." Long the subject of the discussions of metaphysicians and in later times of psychologists, the phenomena of mind have been approached as though they were altogether peculiar in their character and

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being; as though a difference essential and intrinsic separated these phenomena by a wide and hopeless gap from all other phenomena of nature. Let us see whether such an attitude, such a preconceived notion, is justified.

When we turn our attention to some of the lower forms of life, for example, to the protozoa, and notably to the simple expression of life as witnessed in the amœba, we find that the organism reacts in an already complex manner to the environment; thus, when the pseudopod of an amœba comes in contact with a foreign body one of two things occurs: either the protoplasm of the pseudopod flows around the foreign body and thus takes the latter into the interior of its own substance, or the pseudopod is withdrawn. Here we have undoubtedly a "selective" action. If the foreign substance is capable of serving as food, it is appropriated; if not, it is rejected. Should the foreign body be made up both of material capable of serving as food and of material incapable of serving such a purpose, the two are separated; after a time the first disappears, apparently becomes a part of the substance of the amœba; the second is ejected. No one, I believe, would be so ven-

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turesome as to interpret these phenomena as the volitional acts which they so closely resemble. Evidently they are merely the result of the physical (or physico-chemical) reaction of the protoplasm of the amœba with the material of the foreign body. Our increasing knowledge of the functions of the cells in the higher animals has taught us that not only have these cells the special functions pertaining to the tissues of which they are parts but also that they retain, in addition, the primordial property of selecting, digesting, and assimilating their own food. It would appear that the cells of the various tissues possess each a special structure, a special metabolism; that is, each cell contains special ferments by means of which it builds itself up, adds to its own substance out of the general material of the blood plasma. The cells thus have the power of "selecting" foreign materials, of fragmenting them, and of utilizing them for purposes of reconstruction or as sources of energy. The purely physical character of these changes are, of course, beyond question. Fats are split into alcohol and fatty acids; carbohydrates are broken up; albumin is converted into peptones; the latter are split into

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amino-acids and these again into still simpler bodies. In turn, the cells give up into the blood-stream substances so far reduced that they are no longer sources of energy, can no longer play a rôle in the metabolism of the cell.

Not only have the cells of multicellular forms retained the power of selecting, appropriating, and discarding the various materials concerned in their metabolism, but such cells as are not fixed in the tissues, *e. g.*, the white corpuscles of the blood, have retained in addition the power of independent movements and of actually extending and retracting portions of their substance in every way comparable to the pseudopods of the amœba. Surely no one would ascribe the action of the individual cells of the multicellular animals to volition. Both the "selective" action and the power of reducing the material selected into components suitable for appropriation into its own substance are properties inherent in living protoplasm and which the tissue cell shares with the most primitive unicellular forms. No volitional, no so-called "psychic" act can be considered as entering into the phenomena. It seems almost superfluous to repeat that they are clearly the result

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of purely physical and chemical processes. They merely instance the action of colloidal substances upon each other and upon other substances; an action in which the ions of the contained crystalloids no doubt also play a part; in short, the problem is one of chemistry, of electromagnetic or equivalent reactions.

We have in the selection and appropriation of food by the cells of the tissues an instance of the retention by the individual cells of multicellular organisms of the primitive properties of the single cell of unicellular forms. When we turn our attention in multicellular forms to other properties which have likewise to do with the reaction of the organism to the environment, other equally interesting facts become apparent. Let us begin with sponges. According to Parker,[1] "Some sponges, such as the *Stylatella*, appear, when out of water, to be more or less shrivelled or contracted and under other circumstances to be plump and well rounded out. The differences which, for reasons to be mentioned presently, are known not to be due to the simple physical loss of fluid, are apparently

[1] G. H. Parker, Sc.D., "The Elementary Nervous System," Philadelphia and London, J. B. Lippincott Company, p. 26.

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dependent upon a general contractility of the whole flesh of the sponge which, though slight, may nevertheless enable the sponge to change its form somewhat." Again, the dermal membrane of sponges which is a tissue which has not become differentiated into cells, but remains syncytic, has the property of closing the pores of the sponge apparently by flowing over and coalescing, thus forming "over the external end of the pore canal an extremely thin sheet, the pore membrane, near the middle of which the pore has disappeared."[1] The movement of the pore membrane "is hardly to be described as purely amœboid. It seems to represent a stage of differentiation between amœboid motion and simple muscle contraction which may well indicate the kind of contractility that the common flesh of the sponge possesses."[2] In addition, the pores may be closed in some sponges not only by the formation of a pore membrane but also by the closure of the canal leading to the pore—the pore canal—itself. "This is probably due, according to Wilson, to a contraction of the epithelial lining in the pore canal acting after the fashion of a sphincter."[3] The cells of

[1] See Parker, loc. cit., p. 34. [2] Loc. cit., p. 36. [3] Loc. cit., p. 35.

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this epithelial lining "are in every way comparable to a primitive form of smooth muscle-fiber. Their superficial position places them in contact with the water passing through the canal and, as they respond to differences in this water, they are without doubt capable of direct stimulation." To repeat, then, we have in the sponges not only a general contractility of the organism as a whole, together with an amœboid movement of the dermal membrane, but also a sphincter-like action in the canals due to specialized cells. The latter correspond to the smooth muscle cells of other metazoa. They have, of course, no nerve supply and are dependent for their stimulation to contraction on the physical contact with the changing water and its contained substances.

It is interesting to note that in the higher animals muscle-fibers still exist which like these primitive muscle cells of sponges are capable of responding to direct physical stimulation independently of any nervous influence. This has been clearly demonstrated, for instance, by a number of observers to be the case in the iris. In fishes, amphibians, birds and mammals, and probably in the eyes of cephalopods, the sphinc-

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ter of the pupil may be regarded as normally subject to direct stimulation by light, notwithstanding the fact that it is also under nervous control.[1] Similarly, the vertebrate heart muscle appears to be equally subject to direct physical stimulation. While the adult heart is abundantly supplied with nerves and, indeed, itself contains an abundance of nerve-cells, no such facts obtain, so far as is known, in regard to the developing heart of the embryo. Indeed, in the chick the heart appears in about twenty-three hours of incubation and begins to pulsate about six hours later, at a time when the neural crests and neuroblasts have not yet been differentiated. Hence, there is every reason to believe that in the beginning it is absolutely free from possible nervous influence and that its beat is purely myogenic.[2] Many similar instances of muscle activity independent of nervous influence might be cited. It is true apparently of the heart of the tunicate, of the muscle-fibers of the amnion of the chick, and of the circular and acontial fibers of sea-anemones.[3]

We have, then, as one of the primary facts of

[1] See Parker, loc. cit., pp. 50–53. [2] Loc. cit., pp. 53–56.
[3] Loc. cit., pp. 59–61.

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the reaction of the organism to the environment a response in movement. This is expressed in the amœba in the movements of its pseudopods, and, in such multicellular forms as the sponges, in the movements of the syncytic dermal membrane, in the contraction of the cells about the canals, and in the movement of the body of the animal as a whole.

The next question that presents itself is as to the capacity of living protoplasm for the transmission of motion through its own substance. It is not my intention to take up at this point the reaction of protoplasm to light, to heat, to electricity, or to sound, but rather its reaction to those more grossly mechanical forces implied by the impact of foreign bodies. In the sense here employed mere contact implies such an impact. To begin, if transmission of a mechanical impact actually takes place, it would not be surprising to find that this transmission is relatively slow. Proteins are extremely complex compounds. They are made up of many amino-acids; as many as seventeen. Emil Fischer, it may be recalled, succeeded in combining as many as nineteen amino-acids in the synthetic construction of an artificial protein.

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It is a legitimate inference from these and other facts that the structure of living protoplasm is that of an exceedingly complex colloid, the disperse and continuous phases of which must necessarily bear multiple and complicated relations of surface and interfacial tension and of electrical charge to each other. It would seem that considerable time relatively must necessarily elapse for the diffusion or transmission of a mechanical impact through such a substance.

That transmission or diffusion takes place from one part of a protozoan to another part as a result of impact or contact is exceedingly probable. In the amœba the transmission appears to be more or less widely diffused, for not only a pseudopod but the organism as a whole may move toward the food. The diffusion, however, appears to be very slow. In simple multicellular forms such as the sponges transmission likewise takes place. Thus, Parker states[1] that if a pin is stuck into a finger of *Stylatella* at $1\frac{1}{2}$ cm. from the osculum, the osculum will close in about ten minutes; and further, that "the sluggish transmission upon which this reaction depends represents without

[1] See Parker, loc. cit., p. 42.

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doubt that elemental property of protoplasmic transmission from which true nervous activity has been evolved. It may, therefore, not inappropriately be called neuroid transmission."[1] Similarly, in other animals a transmission of motion through non-active and non-nervous protoplasmic tissue can be demonstrated as when motion is transmitted from one field of cilia to another, although quiescent or non-ciliated tissues lie between. According to Parker, "it appears that the ordinary tissues of animals, at least their ciliated epithelia, may exhibit sluggish forms of transmission that are so like those seen in sponges as to admit of being classed under the single head of neuroid transmission."[2]

Obviously, it is greatly to the advantage of an organism when special pathways for transmission are differentiated. Such pathways make their appearance in the primitive nervous apparatus of cœlenterates. This nervous apparatus has been elaborately studied in jelly-fishes and sea-anemones. In the former, impressions—stimuli—upon the marginal bodies are diffused through deeper lying muscle-cells, so that a

[1] See Parker, loc. cit., p. 64. [2] Loc. cit., p. 75.

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contraction takes place in the large circular sheet of muscle that forms the sphincter-like organ midway between the centrally located mouth and the edge of the bell. This contraction reduces the cavity of the bell and by thus driving the water out of this cavity forces the animal forward.[1]

In the sea-anemones an impulse—a mechanical stimulus—applied to the surface of the animal results in a retraction of the oral disc. Investigations have shown that the impulse both in the jelly-fish and the sea-anemone is diffused through a well-defined nervous network. When this nerve tissue is studied it is found to consist of a diffuse and continuous network which also contains cells. The fact that the network is continuous and diffuse suggests an analogy to the syncytic tissue of the dermal layer of the sponges. In keeping, however, with what one would expect, the evolution of special pathways for transmission, leads —judging by the time of the response—to an increased speed of transmission; the response, which is very slow in sponges, is much more rapid in the cœlenterates.

[1] See Parker, loc. cit., p. 103.

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Let us now turn our attention once more to the primitive muscle-cell in the pore canals of the sponges. This muscle, as we have seen, suggests the smooth, unstriated muscle-cell of the higher animals; indeed, such a muscle-cell is still found in some of the tissues of the latter existing as a prototype independent of nervous influence. A muscle-cell independent of nervous influence reacts directly, as we have seen, to a stimulus applied to it. This is unquestionably the case in the muscle-cell in the pore canal of the sponge, in which the stimulus is the flowing water and the substances contained in the latter; similar facts obtain in the case of the other independent smooth muscle-cells that have been instanced. In the sea-anemones and the jelly-fishes, however, the muscle-cell no longer receives its stimulus directly from the environment. There is now interposed an epithelial cell which receives the stimulus and transmits it to the muscle-cell. This epithelial receiving cell acts as a "sense" cell and is termed the "receptor," while the muscle-cell to which it conveys the stimulus is known as the "effector." Later a third structure appears interposed between the receiving cell and the muscle-

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cell. The function of the new structure, a cell termed by Parker "protoneurone," appears to be to diffuse and to distribute to the muscle-cell or cells the stimulus derived from the receiving cell. Its function is that of an intermediary. Evidently we have presented here an arrangement which is the prototype of the sensory, nervous, and muscular system of the higher animals.

Certain other important considerations now present themselves. In the higher animals the nervous system, which in sea-anemones and jelly-fishes is largely superficial, existing in the epithelial layers of the animal, becomes gradually more and more deeply seated and better protected. This is seen in the higher invertebrates and vertebrates alike. In invertebrates there is a gradual retreat, a migration, of the nervous apparatus into the interior of the animal; in vertebrates, as evidenced by embryology, a portion of the epidermal layer, a portion doubtless corresponding to a primitive area of receptor or sensory epithelium, becomes grooved and finally inclosed by the infolding of the edges of the groove.

Interesting as these facts are, a still more

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important consideration remains. The nervous system of cœlenterates, as we have pointed out, consists of a diffuse and continuous network which also contains cells and which is grossly analogous to the syncytic tissue of the dermal layer of sponges. Restating the facts thus far considered, we find that the most elemental form of response by an organism to the environment—next to the movement of the pseudopod of an amœba—consists in the contraction of an epithelial cell, a cell analogous to a smooth muscle-cell, directly in response to a stimulus. The next stage consists, as also pointed out, in the appearance of another epithelial cell which does not itself contract, but receives the impression or stimulus and transmits it to the contractile cell. In this primitive arrangement the first or receiving cell, the receptor, is attached directly to the muscle-cell, the effector. As a matter of fact, a number or a group of receiving cells are attached to a number or a group of muscle-cells. Further, this arrangement "is complicated by the fact that the central branches of the receptive cells are not only applied to the muscle-cells, but form among themselves a network of communication whereby

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the impulses that arise from a few receptive cells may be transmitted to many muscle-cells instead of being limited to a restricted group."[1] The final stage consists in the differentiation of additional cells now interposed between the primitive receiving cell and the muscle-cells. The network now becomes exceedingly complicated, but it presents this distinguishing feature, its fibers are continuous. The cells which it contains are clearly primitive nerve-cells and, as already stated, Parker has applied to them the term "protoneurones." Further, there is no separation of these protoneurones from each other such as occurs in the neurones of vertebrates. There is a free interchange between them of the fibers of the network. There is therefore a wide diffusion of transmission which is totally different from the transmission along definite paths as seen in vertebrates. It is interesting to note, however, in this connection that even in vertebrates nerve nets, diffuse and continuous, are found in certain structures, namely, in the walls of the intestine and in the heart and blood-vessels. The nerve cells found in these structures present all the char-

[1] See Parker, loc. cit., pp. 200, 201.

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acteristics of protoneurones, and as in the cœlenterates form a continuous network.[1]

It is, however, with the differentiated neurone of the central nervous system of vertebrates that we are most concerned. Here the cells which give rise to nerve-cells are in the embryo entirely distinct and separate, and it is only by developing extensions or processes that one nerve-cell comes into relation with other nerve-cells; but there is never any fusion or exchange of fibers between them. Each nerve-cell is a separate and distinct histological integer. It is a unit which is made up of the cell body and the cell processes. By means of the latter it comes into proximity with other nerve-cells often far distant. The processes terminate in brush-like tufts, basket-like formations, and in other ways. The approximated end-formations of two nerve-cells is spoken of very appropriately as a synapse. The nerve-cell, in general terms, is made up of a cell body and two kinds of processes; at one extremity are found one or multiple processes leading to the cell body; these are known as the dendrites; at the other extremity is found a process leading from the cell body; this is

[1] See Parker, loc. cit., pp. 118, 128.

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known as the axone. To this entire structure Waldeyer in 1891 applied the term "neurone," which has been universally accepted and is now in common use. Occasionally there is more than one axone; quite frequently, too, the axone gives off small side branches, usually near the cell body; these are known as collaterals.

For a discussion of nervous function clear conceptions of nervous structure are absolutely essential. To repeat, then, the neurone corresponds morphologically to one cell; it is an anatomical and genetic unit. It comes into close relations with other neurones, but remains anatomically distinct and separate. The point or, rather, the structure at which the juxtaposition of the processes of two neurones takes place—the synapse—assumes, therefore, a special importance in the problem of transmission.[1] Not only the independence of the individual neurone but the presence of the synapse distinguishes the nervous system of the higher animals from that of the cœlenterates, and it

[1] Instead of the cells coming into relation by the approximation of the end-tufts of the axone of one cell to the dendrites of another, the end-tufts of the axone of one cell may terminate about the body of the second cell, but in neither case is there any fusion or continuity of structure.

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may, therefore, be spoken of as a synaptic nervous system in contrast with the nerve-net of the cœlenterates which is essentially syncytic.

A very important fact now becomes manifest. In the nerve net of the cœlenterates transmission is essentially diffuse in character. Only in a very limited degree is the response to a stimulus differentiated. According to Parker, a stimulus—*e. g.*, a fine glass rod—applied to a single spot on the body of a sea-anemone may be followed by a contraction of its whole musculature.[1] However, if the stimulus be less vigorous and limited—*e. g.*, if light be thrown on one side of the animal—it responds usually by turning its oral disc toward the light. Again, stimulation of its tentacles by food will cause its transverse mesenteric muscles to contract and thus open its œsophagus. Further, transmission though diffuse in certain nerve-nets takes place more readily in one direction than in another; *e. g.*, in the tentacles of the sea-anemone, in which transmission is much more freely accomplished in a proximal direction than in a distal one. This slight tendency to specialization in the responses exhibited by the

[1] Loc. cit., pp. 99, 100, 207.

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sea-anemone is to be looked upon as the forerunner of the extremely specialized and limited responses met with in the higher animals. However, while a nerve-net may transmit more freely in one direction than another, it really transmits in all. Transmission in one direction, that is, *polarity* of transmission, exists in a very imperfect degree in the nerve-net. In the synaptic nervous system, however, it is not only established, but is absolute. For example, while it is possible to elicit a response to a stimulus applied in the course of an afferent neurone of the spinal cord, as in obtaining a spinal reflex, no amount of stimulus applied to the efferent neurone, for instance, to the central end of a divided motor spinal root, will elicit any response whatever. Were it not for the synapses and the consequent polarity of the neurone, a stimulus so applied should diffuse to other neurones in the cord; *e. g.*, to sensory neurones and from these again to motor neurones, and thus lead to a response; but none takes place.

It is to the synaptic nervous system of the vertebrates that we will now direct our attention. We have already seen that the smooth

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muscle-cell of the pore-canal of the sponge responds to a direct stimulation. In the cœlenterates a receiving cell is interposed between the muscle and the stimulus. The muscle manifests the response; it is the effector; the receiving cell is the receptor. At the next stage of differentiation, as already pointed out, another cell is interposed which now transmits the impulse from the receptor to the effector. In vertebrates this constitutes the simplest expression of a response, or, to use the physiological term, a reflex. An impression is made on the cutaneous surface, is transmitted along the dendrite of the afferent neurone; thence to the cell body of the latter; thence along its axone to its end-tufts which are in relation with the dendrites of the transmitting cell and form with the latter a synapse; thence to the body of the transmitting cell (the motor cell in the ventral horn of the cord), and thence by the axone of this transmitting cell to the end-plate on the muscle-fiber. The mechanism of the response does not, however, remain as simple as this; for other neurones, intercalary neurones, are further interposed; thus a neurone may be interposed between the afferent cell or receptor, the

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sensory neurone, and the motor neurones. The effect of such an intercalary neurone may be twofold: first, it may reinforce, *i. e.*, increase the volume and intensity of the transmission; secondly, it may come into relation with neurones other than the ones between which it is interposed and thus make possible a more extensive and a more complicated response. An *a priori* consideration would suggest that there are necessarily great variations in the simplicity or complexity of the responses as well as wide variations in the degree with which such responses are fixed or stereotyped. These inferences, I need hardly add, are in accord with fact. In the spinal reflexes, for instance, we have examples of relative simplicity and stereotypy of response. In the knee-jerk we have an example of an exceedingly simple and fixed response. It is invariably the same and independent of volition; it is subject, of course, to variations in diffusion and degree dependent upon secondary factors, but its character never changes. The neural mechanism upon which it depends is relatively simple.

However, the very simplicity and stereotypy of the knee reflex bespeaks a response that has

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become differentiated and limited, and it serves our present purpose merely as offering an example of a simple mechanism of spinal response. It is exceedingly probable that in the course of development differentiations of limited relationships between intercalary neurones and efferent neurones ensued relatively late, and that the primitive arrangement was one which permitted of the more or less wide diffusion of the stimuli received by the afferent neurones. In keeping with this we note in the fish in response to such stimuli movements which involve the musculature of the entire trunk. Evidently the mechanism of response must at first have been very general in character. It must have consisted in the linking of intercalary neurones and the consequent formation of pathways of transmission general in character, and, furthermore, common to the transmission of stimuli received from many different receptors.

Having laid a foundation for the conception of the mechanism by means of which stimuli are received and transmitted, let us now turn our attention briefly to the stimuli which the or-

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ganism is capable of receiving. Thus far we have considered merely the most primitive of all stimuli, namely, contact with foreign bodies. Such contact constitutes an impact grossly mechanical or physical in character. Evidently, living protoplasm is, in addition, exposed to actions that are chemical, to the movements and course vibrations of the medium in which it is immersed, as well as to the various forces that pervade the physical world.

Protoplasm is, of course, destroyed by any chemical action that radically interferes with its structure. Living protoplasm, as pointed out, is an exceedingly complex colloid; it is relatively unstable and is constantly undergoing change. It is being constantly built up and yet is being constantly oxidized and reduced. Such changes necessarily mean an interplay within comparatively narrow limits. If living protoplasm is exposed, for instance, to the gross action of an acid or an alkali, its destruction necessarily follows. There is, however, a wide range in which chemical action can take place without such result. Such non-destructive action would naturally be influenced, first, by the nature of the substance diffused through the

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surrounding medium, and secondly, by the degree of its dilution. The reaction of the protoplasm to such influences cannot, of course, be observed by us through the microscope, but that such chemical actions do take place is evidenced to us in our own persons by our senses of taste and smell. Further, it will become apparent as we proceed that the reaction of the organism to the chemical impressions of the environment have profoundly influenced the development of the nervous system.

When we turn our attention to the movements and vibrations of the medium in which the protoplasm is immersed, we at once find numerous evidences that the protoplasm reacts to such influences. In the very simplest forms, such as the protozoa, the coarse movements of the water—currents and the like—possibly facilitate the changes implied by oxidation, but do nothing else. Soon, however, in the metazoa we observe the appearance of small cavities—vesicles—which contain one or more particles of solid mineral matter and which constitute an apparatus by means of which the movements, the vibrations, of the surrounding medium are taken up—arrested as it were—and thus for-

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cibly transmitted to the body of the organism. Such an apparatus, though it is termed an ear, an otic vesicle, may take up movements far coarser than those which in ourselves give rise to sound. Again, in fishes there is, in addition to a well-differentiated ear, an apparatus which extends in linear form from the head on each side of the body to the tail. It is known as the lateral line system and consists of a tube having at intervals an open space closed by a membrane beneath which is found a structure indistinguishable in its essential features from a macula acustica. Each such macula contains epithelial cells bearing hair-like appendages and each is surmounted by a small jelly-like mass containing a few granules of mineral matter. It is exceedingly probable that this apparatus, existing as it does in addition to the ear, has to do with the reception of vibrations other than those of sound; namely, waves and movements of relatively great length.[1]

It would appear, then, that in addition to the chemical impressions of the environment, the movements and vibrations of the surrounding

[1] See, among others, Dercum, Proceedings Academy of Nat. Sci., Philadelphia, 1879, p. 152.

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medium are taken up in greater or less degree by living protoplasm. These movements seem to play an indifferent rôle in the protozoa and in plant life, but in metazoa an apparatus sooner or later makes its appearance, the function of which is to arrest and to transmit, and, in many instances, to magnify what is purely a mechanical or physical impression.

Similarly, living protoplasm has the function of taking up other incident forces. Especially is this the case in regard to light. The simpler forms of life—*e. g.*, the amœba and other protozoa—are largely transparent to light. It is probable that the light vibrations so transmitted influence notwithstanding the chemical changes in the protoplasm; indeed, this is so evident in plant life as to admit of no question. However, very early we note in many protozoa the appearance of a small mass of red or dark red pigment, a so-called eye spot or stigma, a mass which clearly is not, or is less, transparent to light than the remaining protoplasm, and whose action is apparently to arrest and transform the light vibrations and, possibly, to transmit this transformed energy to the general protoplasmic mass. Clearly we have here a mech-

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anism, a modification of structure, analogous to the formation of the otic vesicle, the function of which with its contained mineral granules (otoliths) is obviously to arrest and transmit coarse physical vibrations.

Heat likewise greatly influences the activity of living protoplasm. The reactions of amœbæ and other protozoa to variations in temperature are well known. Whether in given forms the eye spots, the stigmata, play here also a rôle is not known, though it is, of course, not improbable. However, the presence of the stigmata is clearly not necessary to the temperature reactions of the primitive organism. All things considered, special structures for the "taking up" of heat rays do not appear to be developed until late in the evolution of the metazoa, and our knowledge of them is largely inferential. Regarding their actual existence, however, there can be no doubt; of this our ability to appreciate hot and cold and, indeed, many gradations of temperature, offers indisputable evidence.

A very striking fact now becomes apparent, namely, that the various mechanisms for the special reception of the incident forces of the

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environment are exceedingly small in number. They are limited to receptors for contact, for coarse movements and vibrations of the surrounding medium, for chemical changes, and for the forces of light and heat. This is essentially the arrangement in the higher metazoa and notably in our own persons. This, however, leaves the organism without any provision for the reception—appreciation—of vast ranges of vibrations of whose existence we have in consequence only an inferential knowledge. Besides contact, touch will give us information only of coarse vibrations numbering less than 30 per second; thence, vibrations from 30 to 30,000 per second are appreciated by the ear. Now ensues a great hiatus, for the organism is unable to appreciate any vibrations between 30,000 per second and 3000 billion per second. Vibrations from 3000 billion to 800,000 billion are appreciated as radiant heat; 400,000 billion to 800,000 billion are appreciated as light. For vibrations from 800,000 billion to 6,000,000,000 billion, embracing the ultra-violet rays and the *x*-rays, there is no appreciation whatever.[1]

[1] Herrick, Introduction to Neurology, second edition, p. 77.

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When we consider the vast range and number of the forces at work in the universe, the exceedingly limited capacity of the organism to become cognizant of its environment becomes very apparent. Living protoplasm fails utterly to develop receptors for these unnumbered manifestations of energy. Protoplasm seems to be "transparent" to them. Have we not a hint here as to the structure of protoplasm? If deluged by them in great volume it may be destroyed, but as ordinarily exposed in the course of nature to electricity, the ultra-violet ray, the *x*-ray, and other rays it remains unaffected. It is very suggestive, too, that it is practically transparent to light rays and is obliged to develop a pigment, the stigma, the visual purple. Similarly, it is largely negative to coarse vibrations and requires the development of a vesicle with its contained otolith.

In order that the significance of the above facts may be fully appreciated let us recall to our minds once more the nature of living protoplasm. It is, as we have already pointed out, an exceedingly complex colloid, built up of many complex amino-acids distributed through varied disperse and continuous phases. It is a very

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unstable compound, for it is constantly undergoing changes. It is constantly being oxidized and reduced, but is as constantly being built up. Foreign materials, proteins, fats, and carbohydrates are through its fermentative (*i. e.*, chemical, electro-physical) action fragmented until they become identical in character with the molecules of the original protoplasmic mass and become part of its substance. During this process and in the further continuance of the chemical change, that is, in the continued process of oxidation, energy is liberated. The older particles are finally chemically so far reduced that they become inert and then spontaneously make their exit by solution into the surrounding medium. It is this continuous chemical change with its accompanying evolution of energy that constitutes the phenomenon presented by living matter.[1]

Evidently, if so complex and unstable a compound as living protoplasm when first evolved had been vulnerable to the innumerable incident forces of the universe, it could never have survived. Curiously, it has been almost

[1] The mineral salts—ions of the crystalloids—undoubtedly arrange themselves during this process in accordance with electrophysical principles, and no doubt play an important rôle.

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wholly negative in its reaction to these. Extremes of heat and cold, coarse physical destruction, have been the most it had ordinarily to contend with. Excessively rarely have other agencies interfered with its existence. Its very "transparency" has been its salvation. Perhaps it is its complexity, its semifluidity—its very inability to take up manifold modes of motion—its colloidal plasticity, its peculiar molecular structure, that have made possible the passage through it of such a vast array of forces without change in its substance. After all, these forces do influence it and play a rôle in its physics and chemistry, but certainly that rôle, as it occurs in nature—not in the laboratory—is not a destructive one.

We have already considered (see p. 23) the evolution or adaptation in metazoa of a surface cell to receive external impressions, *e. g.*, of contact, and which receiving cell (receptor) transmits the impact or impulse to a contiguous contractile cell (muscle-cell, effector) either directly or it may be through an intermediate cell or cells. Evidently these primitive surface cells were capable of receiving all of the impressions which the protoplasm itself was cap-

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able of receiving. These impressions consisted primarily of those of contact and of coarse vibration. That substances contained in the medium in which the organism was immersed also affected the surface cells chemically is extremely probable. It seems equally clear that the surface cells were also affected by the vibrations which give rise to sound and by those which give rise to heat and light. In both of the latter instances, however, it is evident that the degree and extent in which the impacts could be taken up depended upon the presence of special and probably, at first, purely incidental factors; on the one hand, on the presence of coarse mineral particles, and on the other of particles of pigment; *i. e.*, of particles derived from the original protoplasm and so changed as to be able to arrest in a measure the incident forces.

In addition, then, let us repeat, to contact and coarse vibrations, the primitive surface receiving cell also received those impacts termed "chemical." These impacts, molecular in character, are those which, as already pointed out, give rise in ourselves to the sensations of smell and taste. It would seem that the reception of

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chemical impressions was almost as primitive if not quite as primitive a quality as the reception of contact and coarse vibrations. On *a priori* grounds we would almost expect the chemical sense or senses to have assumed a relatively high degree of importance; and this, indeed, is found to be the case, judging from the facts of vertebrate morphology. It would appear that relatively early certain receiving cells became especially adapted to receiving chemical impressions and that this finally became their special and sole function. It is important at this point to note a distinction between the senses of smell and taste. The sense of smell is excited by objects external to the organism, usually by objects at some distance, and the impressions received from which cause the organism to approach or to move away from the object. The sense of taste, on the other hand, deals with objects that have entered the oral cavity or at least come into close contact with it and which bring about responses within the body of the animal, namely, visceral responses dealing with digestion. As expressed by Sherrington, the sense of smell is exteroceptive, while taste is interoceptive. Clearly, it is the extero-

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ceptive sense of smell which deals directly with the environment and as such it greatly outranks in importance the sense of taste. In keeping with this we find in fishes that almost the whole of the cerebral hemisphere is an organ of smell, while the portion devoted to the sense of taste is much smaller and appears to be in close anatomical relation with the portion —the visceral area[1]—devoted to impressions received from the viscera. However, in fishes the receptors for taste are found also outside of the oral cavity about the mouth and, indeed, in some forms are rather extensively distributed externally; so that in fishes the sense of taste is not as strictly interoceptive as with ourselves, but also in part exteroceptive. The great importance of smell as an exteroceptive sense becomes evident when we reflect upon the very great range in the number and variety of the impressions, the infinitely small size of the particles concerned, and the relatively great distance at which they may be appreciated. Taste, on the other hand, has to do only with substances in immediate contact with the receptors, while the variety of impressions pos-

[1] See Herrick, loc. cit., pp. 119, 273.

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sible is exceedingly small; namely, merely salty, sour, bitter, and sweet. Flavors, it should be remembered, are appreciated only through the sense of smell.

Just as in the course of development special receptors were differentiated for chemical impressions, special receptors were differentiated for the reception of sound and light, and to which have been adapted various structures for intensifying and elaborating the impressions received. A consideration of the latter factors would take us too far afield and, further, is not necessary for our purpose. Suffice it to say that highly specialized receptors with highly complex additions have in the course of time made their appearance, and that they are all expressive of a common truth, namely, that they receive and transmit into the interior of the organism certain definite impacts from the external world. That there are more than five pathways for the ingress of these impacts need not here be pointed out; the consideration of others than those thus far discussed may be safely deferred for the present.

Having emphasized the purely physical character of the rôle played by the receptors, let us

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turn our attention once more to the transmission of the impacts through the organism. How does the organism respond to the multitude of impressions received? What are the reasons therefore? In how far are responses fixed? In how far are they variable?

The simplest form of response, as we have already seen, is the response of a muscle-cell to direct stimulation; the next in the course of evolution is the reception by an epithelial cell, a receptor, of the impact, and the transmission of the latter to a contiguous muscle-cell, an effector; the third state consists in the interpolation between the receptor and the effector of another cell whose function is that purely of transmitting the impact from the first cell to the second. This third cell may have relations, however, with several effectors, and thus the response induced may be less simple and proportionately extended. This intermediate cell has been termed by biologists the "adjustor." It should, of course, have a definite name, but to the writer it has seemed that the word "adjustor," implying as it does independence of action or possibly volition, is open to objection. The action of the intermediate cell is purely

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physical and, needless to say, automatic. Its presence, however, opens up, as we will see, enormous possibilities as to the degree and the character of the response. As already pointed out (see p. 31), other transmitting cells, intercalary neurones, are in the course of development farther interposed. The rôle of the latter in increasing the volume and intensity of the transmission and in adding to the complexity of the response we have already indicated.

Evidently the presence of the intercalary neurones has made possible the establishment of definite pathways of transmission. Impacts derived from many sources would tend to form average pathways of transmission to the effectors. To use the words of Sherrington, "That portion of the synaptic nervous system which is termed 'central' is the portion where the nervous paths from various peripheral organs meet and establish paths in common, *i. e.*, *'common paths.'*" The central nervous system of vertebrates is primitively a longitudinal tubular structure which lies above another longitudinal tubular structure upon which the nutrition of the animal depends, namely, the alimentary canal. The material admitted to

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the latter traverses its entire length. Evidently the reception of material which may serve as food is of primal importance to the animal. Given the "polarity" of the latter—*i. e.*, the differentiation of a cephalic and a caudal extremity—it follows that the interplay of receptors and effectors to bring about the intake of food at the cephalic end is a necessary outcome of the action of the individual receptors and the establishment of common paths of transmission. The primitive nervous system of vertebrates was in its essentials a tube in which the nerves coming from the peripheral surfaces terminated synaptically in neurones in the walls of the tube; probably there was an arrangement in segments, certain nerve aggregations corresponding to certain areas. These tubal centers were doubtless connected with each other by intercalary neurones which communicated synaptically with each other to form "internuncial paths." In this way many muscles would probably be made to respond simultaneously or successively to an impression made upon a limited number of cutaneous receptors. If we turn our attention to the cephalic end of the animal, we note the presence of certain aggregations of

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neurones about the tube which stand in definite relation to certain receptors situated about the head, the relation being very much the same as the segmental relation in the tube lower down. Here, to restate the fact, definite cutaneous levels of receptors are related to the neurone aggregations at the same levels, each such arrangement constituting a segment.

The first aggregation of neurones that we meet with in the primitive vertebrate forms is that constituting the olfactory lobe which is in close relation with the receptors in the olfactory mucous membrane. Back of the olfactory lobe we note the presence of a lobe related to the receptors in the eye; next an aggregation related to the receptors in the ear, and so on. Naturally these facts find their simplest expression in the fish. Speaking of the dog-fish, Herrick states[1] that we may recognize in this fish a "nose brain," an "eye brain," an "ear brain," a "visceral brain," and a "skin brain." Each "brain" is related, let us repeat, to certain receptors and to these only. Further, each set of receptors and its corresponding central neurones is adapted to the reception of certain im-

[1] See Herrick, loc. cit., p. 121.

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pacts or stimuli only; thus the receptors for the olfactory lobes can receive only chemical impressions; the receptors for the optic lobes only the impacts of light; those for the ear only the impacts of sound, and so on. In other words, each receptor can accept only its own special stimulus; the latter is known technically as the "adequate" stimulus.

We are impressed at once by the relatively enormous size in the fish of the olfactory lobes. We are justified in inferring that the chemical sense in fishes is most important. Its receptors are placed immediately above the oral cavity and its function in the approach of the organism to food and in the intake of food is quite obvious. We note that the chemical impacts, *i. e.*, odors, are often received from great distances. The question arises why does the organism as a whole respond to the reception of such impacts by an approach? Here we are forced in a measure into the field of speculation. However, the phenomenon must be purely physical and therefore capable of a physical interpretation. Once more we are referred to the reactions of living protoplasm to the impacts of the external world. Evidently these impacts

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which merely affected the protoplasm of the receptors for good or for ill, but for those which affected the tissues of the organism as a whole. While the reader may find objection to the above explanation, the fact remains, I think, beyond reasonable question that the approach or retreat of the fish in response to olfactory impressions is a purely automatic phenomenon.

When we turn our attention to the eye, the ear, and the lateral line system of the fish, other important and interesting facts suggest themselves. Thus it is exceedingly probable that the field of vision is primarily one for the perception of moving objects rather than for those which are stationary. Food, already perceived by its odor, makes also in moving an impression on the retina. Owing to the internuncial pathways the action of the olfactory apparatus in bringing about contraction of the muscles in swimming would now be reinforced. A similar effect would be exerted if the object also made a sound and so excited the ear, or produced coarse waves in the water and so excited the lateral lines.

Whatever explanation we adopt, whether we consider the olfactory impacts—the chemical

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molecular movements of smell—as establishing a line of least resistance, or whether we adopt the explanation of these impacts establishing an "attraction," the conclusion is alike inevitable that the resulting approach of the fish toward the food is, let us repeat, automatic. Similarly the reaction of the other "brains" to their special receptors—the eye brain, the ear brain, the skin brain—must be alike physical and automatic.

It may, I think, be safely assumed that the other functions of the fish in which the nervous system plays a part, such as digestion, respiration, circulation, and nutrition, are similarly automatic; in fine, that all the neural functions are automatically performed. The question arises can we draw a like conclusion as regards the nervous system of the higher vertebrate forms, including man? Let us see what the facts justify.

The automatic character of a spinal response or reflex must be admitted without question. Secondly, this response is fixed and invariable. A similar interpretation must, I think, be extended to the responses which involve the brain stem, namely, the medulla, the pons, the crura

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cerebri, the thalamus, and the corpus striatum; indeed, the brain stem is frequently spoken of as a segmental apparatus, just as we apply the conception of a segmental apparatus to the spinal cord. It is also spoken of as the palæo-encephalon (Edinger) as it represents the primitive vertebrate brain. To the brain stem we must add the cerebellum whose activities are alike "invariable, innate, structurally predetermined."[1] This leaves us as the only structure permitting a variable response the cerebral cortex.

It may be here noted that such modifications of the invariable response as an animal betrays in its behavior under changed external conditions, such as absence or surplus of food or of oxygen, or such changes in response as may have their origin in changed physiological states within the organism itself, are not here included in the expression "variable" response, but rather such responses as would suggest, other things equal, a volitional act, *i. e.*, "choice" on the part of the animal. "Choice" in this sense is manifested by such elementary forms as the amœba, and, as we have seen, by the individual

[1] See Herrick, loc. cit., p. 124.

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cells of the body tissues. How this apparent choice is to be explained on purely physical and chemical principles we have also seen. Let us now take up the "variable" responses of the higher vertebrates for detailed consideration.

The end of the primitive neural tube, the telencephalon, also spoken of as the neo-encephalon, has no segmental relationships. It can, therefore, only be in relation with, and grow in relation with, the other portions of the neural tube. Its neurones in their development and multiplication can only establish relationships with the neurones of the primitive segmental brain; ingress and egress are possible only through the latter. Not having segmental relationships, the neurones of the end-brain are necessarily limited to the function of intercalary neurones. If the end-brain grows in response to the stimulus of function—and the facts of embryology, comparative anatomy, and paleontology show that it has so grown—it means that a multiplication of intercalary neurones has taken place, and as a corrollary an increasing variability—that is, an increasing "adaptability"—of response. An increasing adaptability of the responses of the organism to the con-

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stantly changing condition of its existence can only become possible through the multiplication of intercalary neurones. This multiplication permits alike of an increased complexity and an increased adjustment of the responses. Finally, it is obvious that in speaking of the function of the end-brain, the cortex, we should speak not of the variability of the responses, but of the *adaptation* of the responses.

In turn, it becomes evident that the responses of the end-brain, the telencephalon, have their origin in the relation which its neurones bear to those of the primitive segmental brain, to the neurones of the spinal segments, and to each other. Transmission into the end-brain takes place through the "between brain," the thalamus. Here we find that through the development of intercalary neurones, special way stations, nuclei, have made their appearance. In the cells of the latter various axones bearing tactile, visual, auditory, and other impacts terminate synaptically; thence other axones constituting the so-called "sensory projection fibers" pass upward to the cortex. The nuclei in the thalamus which play this rôle of way stations—and one of whose functions is doubtless that of

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reinforcement—are spoken of as "cortical dependencies"; in vertebrates lacking a corresponding cortical development they naturally have no existence.[1]

Responses make their exit from the cortex in axones which terminate synaptically not in neurones in the corpus striatum but in neurones in the brain stem and spinal segments. The latter group of axones constitute the motor projection fibers and are also spoken of as the upper motor pathway or pyramidal tract. Like the nuclei of the thalamus, the neurones of the corpus striatum doubtless have an action of reinforcement, but it is probable that they do much more than this; in lower vertebrates their nuclear arrangement appears to be such as to permit of relatively complex responses; for example, in birds, in whom the striatum is large and the cortex meagre. In higher vertebrates they appear to constitute a ready-made mechanism (neurone combinations) for various automatic movements controlled or inhibited by the cortex; certain it is, also, that the corpus striatum is in part concerned in the purely dynamic

[1] All of the afferent impulses save those coming from the olfactory lobes find their way into the telencephalon through the thalamus.

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function of the maintenance of muscle tone. It is clearly evident that in the higher vertebrates such responses as have their origin in the striatum or are transmitted by it are definitely *fixed;* on the other hand, such responses as arise in the cortex and are transmitted by the axones terminating in the brain stem and spinal segments are variable or adaptable. The responses so transmitted are adapted to the environmental happenings. They are the resultants of, and, other things equal, equivalent to, the various and multiple impacts received by the organism.

Having established the avenues of ingress and egress and having considered the nature of the responses, the question now arises, What takes place in the cortex itself? The sensory projection fibers terminate synaptically in certain regions or areas of the cortex. These areas are commonly spoken of as cortical centers for smell, taste, vision, hearing, tactile, and other impressions. For the present it will suffice to regard them purely as gateways or avenues of entrance to the general cortex. Similarly, the neurones of a certain area—that of the ascending frontal convolution in man—give rise to axones which constitute the motor projection

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fibers. This leaves extensive regions which have no access to the external world either in the way of receiving impacts or of transmitting them save through such connections, direct or indirect, as they may have with the receiving or the emissive areas. The facts of anatomical structure show that there are extensive and numerous pathways—association tracts—which connect different parts of the cortex with each other. Some of these fibers form extensive and long bundles or fasciculi; others are relatively short; others still connect immediately or closely adjoining areas of the cortex. In fact, the arrangement is such that any one part of the cortex is directly or indirectly connected with every other part. Finally, extensive commissural fibers bring about an intimate union of the two cerebral hemispheres. When we reflect that the human cortex contains upwards of ten thousand million neurones[1] and that each neurone bears numerous dendrites and that each neurone sends out one axone, sometimes two, and several collaterals, all terminating in numerous tuft-like subdivisions, we can realize that the

[1] According to Herrick, loc. cit., p. 27, "some 9280 million," *i. e.*, approximately 10,000,000,000.

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number of possible combinations becomes almost infinite. That this leads to great "variability" of the response, or to restate the fact in other words, to great possibilities in the *adaptation* of the response becomes very evident. A given adaptation, as we will see later, is the resultant of the impacts received and of the previously existing cortical neuronic combinations. Finally, the conclusion is inevitable that the response to the impacts must be automatic. Such response is clearly automatic when but one neurone is interposed between a receptor and an effector, and the factors do not change when the interposed neurone becomes multiple.

A further fact now becomes apparent, namely, that as a result of a given impact a very large number of neurones may and probably do become involved in the transmission; the transmission doubtless takes place not only through many hundreds, but through many thousands of cortical neurones. In the course of the transmission a gateway of exit is finally reached, and thence a response is transmitted via the brain stem or cord to the effectors.

Another inference now presents itself, an inference unavoidable and conclusive, and which

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is of the very greatest importance; and that is, if the response is "variable," if it is "adjustable," and therefore capable of change, the neurones of the cortex cannot bear the same fixed relations to each other as do the neurones of the brain stem and cord.

Many years ago—in 1895—in thinking over the problems presented by hysteria, it occurred to the writer that possibly a hysterical paralysis —*e. g.*, of an arm—could be accounted for by a retraction of the processes of the neurones in the "arm center" of the motor area of the cortex, so that these neurones would no longer be in physiological relation with the rest of the cortex. In other words, it occurred to the writer that possibly the neurones of the cortex had some power of movement as far as their terminal processes, the dendrites, and end-tufts are concerned; so that the latter could in some degree be retracted or extended. An examination of the literature revealed that the idea of movement on the part of the neurone had already occurred to three other writers, one in Germany and two in France. The first to advance such a view was Rabl-Rückard,[1] who in 1890 sug-

[1] Rabl-Rückard, Neurolog. Centralblatt, April, 1890, p. 199.

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gested that nerve-cells have an amœboid movement; and he, at the same time, pointed out the significance of such a view in enabling us to explain the mechanism of psychic processes. His ideas attracted no attention, but in 1894 Lepine,[1] in a paper on a case of hysteria of a peculiar form, advanced practically the same theory. His idea was that the neurones were capable of movement, and to such an extent as to enable them to alter the degree of their relation to each other. Some six months afterwards another French writer, Mathias Duval,[2] advanced the same theory in a communication made to the Société de Biologie. Lepine had been unaware of the theory advanced by Rabl-Rückard and Mathias Duval, and was equally unaware of the views advanced by Lepine. A week after Duval had advanced his theory, Lepine,[3] before the same society, repeated his former arguments in its support. I myself presented the theory of the movement of the neurone in a paper read before the College of Physicians of Philadelphia in January, 1896,[4] and in

[1] Lepine, Revue de Médecine, Aout, 1894, p. 713.

[2] Duval, Comptes Rendus de la Société de Biologie, Février, 1895, pp. 74, 86.

[3] Lepine, Comptes Rendus de la Société de Biologie, 1895, p. 85.

[4] Trans. College of Physicians, Philadelphia, 1896.

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June of that year read an address on the same subject before the American Neurological Association.[1] In the meantime, in the spring of 1896, the theory had been again advanced by two other French physicians, Azoulay and Pupin. This view was not accepted by Ramón y Cajal.[2] He, however, saw the necessity of admitting a change in the relations of the neurones to each other, and offered the explanation that it was the neuroglia cells which moved and not the neurones. He maintained that the processes of the neuroglia cells represent an insulating and non-conducting material, and that during the stage of relaxation these processes penetrate between the arborizations of the nerve-cells and so make difficult or impossible the passage of nerve currents; on the other hand, in the stage of contraction the processes of the neuroglia cells are retracted and they then no longer separate the processes of the nerve-cells, and the latter are thus permitted to come into contact. Evidently Ramón y Cajal admitted the very thing against which he contended, for if the nerve-cell processes are at one time not in con-

[1] Trans. Amer. Neur. Assoc., August, 1896.

[2] Ramón y Cajal, Revista de Medicina y, Cirugia Practicas, Mayo, 5, 1895, p. 497.

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tact and at another are in contact, they certainly move. It matters not whether the motion is an active or a passive one. Finally, while movements of neurones have not been observed in vertebrates, one very suggestive observation was made in 1890 by Wiedersheim.[1] He saw in the living animal, an entomostracan, *leptodora hyalina*, the nerve-cells in the œsophageal ganglion move. The œsophageal ganglion may in a sense be regarded as the brain of the animal, inasmuch as it receives the fibers of the optic nerve, and Wiedersheim actually saw these cells move and change their shape. He described the movement as slow and flowing, and pictures in his paper the various shapes assumed by the nerve-cells at different times. While it is a far cry from the nerve-cells of invertebrate forms to those of the vertebrates, the nerve-cells of the former, the protoneurones, illustrate, as we have seen, elemental truths, and the observation of Wiedersheim is in harmony with the view that the relations of the primordial neurones are not fixed as we find them in the segments of the cord and brain stem of vertebrates, but permit of change with each other. It would appear that

[1] Wiedersheim, Anatomischer Anzeiger, 1890, p. 693.

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this motility or facility of change lost in the cord and brain stem has been preserved in the telencephalon.

Further, we are so in the habit of looking at nerve-cells in mounted and stained sections of the cord and brain that we are apt to transfer the idea of fixation of structure subconsciously to our conceptions of the living cells and processes, and to overlook some of the marvelous truths which they present. The neurone has its origin in a simple undifferentiated cell, the neuroblast; in the course of its development it sends out processes, some of them of enormous length, which in their growth often pass along devious routes to a definite destination. For instance, certain cells of the motor area of the cortex send forth processes, the axones, which grow through great distances to come finally into relation with neurones in definite segments of the spinal cord; and again, other neurones, both motor and sensory, send out processes which bring the various portions and areas of the body into definite relations with them; that is, the axones grow out until they reach definite effectors or definite end-organs of the body surface and elsewhere. That this phenomenon

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must be the expression of purely physical or chemical causes there can be no doubt. Definite causes must be at work, such, for instance, as determines the growth of the roots of plants toward water. "Many organs of the adult body are known to secrete specific soluble chemical substances termed 'hormones,' which diffuse throughout the lymph or blood and call forth functional activity in remote organs. It is possible that during development of the body, the organs, as soon as definite stages of growth are reached, secrete similar substances which diffuse through the surrounding tissue and each of which has a chemotactic affinity for a certain type of developing neurones. Thus, the developing muscles may secrete a substance to which the motor neurones of the spinal cord react by a growth of their embryonic axones toward the source of the stimulating material."[1] This phenomenon is known as chemotaxis. The thought also suggests itself that possibly this process does not cease absolutely with the evolution of the organism, but in some measure continues in the fully developed organism in accordance with changing conditions.

[1] See Herrick, loc. cit., pp. 111, 112.

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Again, it has been found that in the course of the evolution of vertebrate forms nerve-cells change their positions. Numerous groups of cell bodies with specific functions move from their primitive positions to new locations. Our knowledge of their migrations is due mainly to Kappers. It would seem that cell bodies "tend to migrate in the direction from which they habitually receive their stimuli, *i. e.*, in the direction taken by their dendrites. If there is a change in the direction from which a given nucleus (*i. e.*, a group of cells) receives its chief stimuli, the nucleus as a whole will tend to move toward the new source of excitation and away from the old.[1] The change in position is obviously expressive of a physical reaction to a stimulus, and the phenomenon has received the name of "neurobiotaxis." Both the facts of chemotaxis and neurobiotaxis throw an interesting light on the active, living, growing character of the neurone; changing and capable of change. Indeed, capacity for change and adaptation seems inherent in the primitive neuroblast. At times continuous changes and fresh adaptations may be the result; at others,

[1] See Herrick, loc. cit., p. 112.

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fixation or relative fixation may be established.

Let us again turn our attention to the relations between the neurones, *i. e.*, to the synapses. Kappers[1] points out that the relations of neurones to each other vary somewhat. In some the relation may be practically one of continuity, as when the neurofibrils of one neurone pass directly into those of the second; as is often the case in the vestibular apparatus. Such an arrangement may be expected in the Mauthner cell in the catfish—a large cell in relation with the vestibular nerve—in which transmission probably takes place directly between the axones of one cell and the dendrites of another. Between other cells the relation may be merely that of contiguity or, it may be added, of propinquity. At the time of the passage of a reflex a delay in transmission occurs at a synapse. Kappers thinks that differences in delay may be due to differences in the synapses. Probably this delay is greater when the histological relation consists merely of contiguity and greatest when this contiguity or approxi-

[1] Kappers, Versuch einer Erklärung des Verhaltens an der Synapsis, Psych. en Neurol., Bladen, 1917, H. 6, p. 440; also Brain, July, 1921, p. 125.

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mation must first be established. The last would naturally result when a new pathway was being formed, or in the case of one that was only occasionally used. Kappers regards the transmission through the neurone in one direction only—*i. e.*, the polarization of the neurone—as a neurobiotactic phenomenon. He declares that the formation of dendrites and axones is the result of the reaction to stimuli; the axone is a formed product of the stimuli current; it grows with the current, is formed by the current. The dendrite is likewise a formed product of the stimuli current. In the passage of the current from cell to cell, the axone terminals of the first cell are drawn toward the dendrites of the second cell, and the dendrites of the second cell are drawn toward the axone terminals of the first. The mere act of the transmission of an impulse brings about an approach, the whole process being neurobiotactic.

Sherrington[1] regarded it as improbable that the phenomena of the synapse are dependent upon an amœboidism of the neurones, and he did so for the following reason: The length of the delay caused in a reflex by a synapse—*i. e.*,

[1] Sherrington, The Integrative Action of the Nervous System, 1911, p. 24.

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the latent period—is inversely proportional to the intensity of the reflex. Sherrington found that if the latent period of a reflex produced by delivery of the stimulus in its full strength be compared with the latent period of the reflex produced in two stages—*i. e.*, by an "initial" stimulus and an "incremental" stimulus—the latent period resulting in the two stimuli reflex is longer than in the first, namely, when only one maximal stimulus is applied. This result he regarded as an argument against an amœboid movement on the part of the neurones; a bridge once having been constructed by the initial stimulus, there should be no additional loss of time. However, Sherrington's results also showed that the latent period of the incremental stimulus is always shorter than that of the initial stimulus. As Kappers points out, this fact can only be explained by supposing that something takes place as a result of the initial stimulus which does not take place as a result of the incremental stimulus; and to Kappers there seems no good reason for supposing that the added time of the initial latent period is not consumed by the approach of the colloidal particles of the terminal processes. Kappers declares

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that the amœboidism, and, in any case, the neurobiotactic phenomena of nerve-cells, have not for a long time been mere hypotheses, but are actual facts.

The interrelations of the neurones have been the subject of much speculative thought and study. Sherrington who, as just seen, denies the amœboidism of the neurone, expresses himself as follows:[1] "At the nexus between cells, if there be not actual confluence, there must be a surface of separation. At the nexus between efferent neurone and the muscle-cell, electrical organ, etc., which it innervates, it is generally admitted that there is not actual confluence of the two cells together, but that a surface separates them; and a surface of separation is physically a membrane."

"If the conductive element of the neurone be fluid, and if at the nexus between neurone and neurone there does not exist actual confluence of the conductive part of one cell with the conductive part of the other—*e. g.*, if there is not actual continuity of physical phase between them—there must be a surface of separation. Even should a membrane visible to the micro-

[1] See Sherrington, loc. cit., pp. 16, 17.

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scope not appear, the mere fact of non-confluence of the one with the other implies the existence of a surface of separation. Such a surface might restrain diffusion, bank up osmotic pressure, restrict the movement of ions, accumulate electric charges, support a double electric layer, alter in shape and surface tension with changes in difference of potential, alter in difference of potential with changes in surface tension or in shape, or intervene as a membrane between dilute solutions of electrolytes of different concentration or colloidal suspensions with different sign of charge."

Regarding this hypothetical membrane Kappers is of the opinion that by a synaptic membrane we need not understand an actual membranous structure, but "merely an electro-endosmotic layer." Again, obviously such a membrane if morphologically demonstrable would consist of the apposition or fusion of two cell walls and, further. the physical principles involved—endosmosis and the possible passage of electrically charged ions—would apply especially to neurones with fixed synaptic relations and perhaps in less degree to neurones whose relations were changeable. In any event,

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it is quite probable that the physical principles involved would not differ in essence from those that determine the approach of the pseudopod of an amœba to a nitrogenous or other food particle.

Leaving for the time being the consideration of this "electro-endosmotic layer" or synaptic "membrane" and the consideration of the physical or chemical principles involved, let us turn our attention once more to the reactions of the cortical neurone, the neurone of the telencephalon, to the stimuli, the impacts, transmitted to it from the segmental brain. In one of my earlier papers, read before the American Neurological Association in June, 1896, I thus expressed myself:[1]

"A sequence of sound vibrations impinging upon the peripheral auditory neurones produces in them a change, which in turn affects the relations which their neuraxones bear to the auditory nuclei, and secondarily to the auditory cortical neurones. Not only are the latter affected by the impressions received from the afferent neuraxones, but they, in turn, re-

[1] Dercum, [Presidential Address delivered before The American Neurological Association (The Functions of the Neurone), The Journal of Nervous and Mental Disease, Vol. XXI, No. 8, 1896, p. 522.

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act in such a way as to change their relations to each other, and the new positions assumed by them will depend largely upon the fact as to whether a similar sequence of impressions has passed through them before. If so, the old combinations will be re-formed. From the cortical auditory center there now pass through the general cortex a series of combinations among the neurones, also along the oldest and best-travelled lines, so that a given sequence of musical sounds may suggest at first a familiar air, a moment later a vivid recollection of an opera once heard and seen. In this simple illustration is embraced the physiology of perception, of conception, of memory, and the explanation of the very sequence of thought itself."

Setting aside for the time being the discussion of the factors of sensation and of consciousness embraced in the above interpretation, let us take up more in detail the various other phenomena presented. First, we are impressed by the fact that time is consumed in the transmission of the impact from the moment of its reception until it finds motor expression. This is known as the reaction time. We have

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already briefly considered the delay which occurs at a synapse. It appears to be time consumed in the preparation of the synapse for transmission, *i. e.*, in the "setting" of the synapse (to use Sherrington's term), and which consists possibly in the formation of protoplasmic extensions, in the passage of ions, or in the establishment of induction. Many studies have been made as to the time lost in the passage through gray matter of various reflexes, and it would appear that the simpler the reflex, the shorter the reaction time, and the more complex the reflex or response, the longer the reaction time; thus a simple spinal reflex in the frog reveals a loss of 0.008 second (Wundt) or 0.014 and 0.021 second (Buchanan), while the simplest reaction times measured in the psychological laboratories vary between 0.1 and 0.2 second,[1] and the reaction times as measured by physicians between a "stimulus word" and a "reaction word" range from one to two seconds and sometimes longer. The time consumed is evidently lost in some physical process, as already indicated. The transmission of impact from neurone to neurone means the overcoming

[1] See Herrick, loc. cit., p. 104.

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of inertia or resistance at the beginning of each neurone, *i. e.*, at its dendrite. Each synapse, so to speak, presents a new "neurone threshold" (Sherrington).

The positions of neurones and their relations to each other are, as we have seen, determined by the principle of neurobiotaxis. According to the latter, the dendrites are directed or, rather, are drawn toward the sources of stimulation, *i. e.*, the sources from which the impacts are received; the axones likewise are drawn toward the dendrites of the succeeding cell and, in given instances, in the course of phylogeny even the entire neurone may move. Here we are concerned, however, merely with the behavior of the dendrites and axone terminals. No doubt the transmission, the diffusion, of an impact, to definite neurones, is determined by neurobiotactic principles, and in this is to be found the explanation of "association." In their early phylogenetic relationships the transmission of impact from neurone to neurone was doubtless determined by propinquity, and in the multiplication of intercalary neurones there gradually appeared the "common paths" (see p. 48). Definite groups of neurones, therefore,

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became associated in the transmission of given impacts, *e. g.*, of sound, as in the illustration quoted above. The transmission did not, however, cease in the so-called cortical center for hearing in the temporal lobe, but was transmitted along "association" paths to other regions of the brain. What determines the direction of the transmission? Why do the impacts break through definite thresholds and thus give rise to certain associations? Doubtless the tendency in the primitive nervous system was to a general diffusion of impacts, but automatically, as in the instance of the establishment in the fish of the common effector paths concerned in swimming as a result of the common action of the receptors of smell, sight, and hearing in determining the approach of the fish to food (see p. 54), so impacts entering the cortex by way of the organ of hearing would probably diffuse more readily toward the cortical areas for vision than to those of touch, smell, or taste; as in the higher vertebrates, impacts of sight and sound from a given source are very frequently simultaneous. That there should be a lowering of thresholds between simultaneously aroused groups of neurones would

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naturally follow. Activity of neighboring groups of neurones would necessarily mean an increased amœboidism. If one group only be aroused, pathways having once been established, there would be a transmission to the others which were still quiescent. At any rate, whatever be the explanation, it can, I think, be safely assumed that association—*i. e.*, transmission to other neurones—takes place in accordance with physical principles, and, second, having once taken place, they take place more and more readily with repetition. In other words, to use a physiological term, they become "facilitated."

The special trend followed by the cortical neurones in their transmission-associations doubtless depends upon a number of factors. If the experiences are old and often met with, the same or similar associations are repeated; if they are new experiences, no doubt new combinations are formed, new pathways established. It is probably this quality of neurone activity which makes possible additions to our knowledge; it becomes thus the basis of all training and education.

However, the function of the neurone of the

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cortex is not merely that of transmission. The reception of the impact means not only the passage of the latter through dendrites, cell body and axone, but also a change in the substance of the neurone; a change physical and chemical which results in the evolution of energy. An active consumption of substance, probably the result of an increased oxidation, takes place, and a corresponding amount of energy is added to the impulse transmitted. It is easy to understand that when the latter finally reaches the effectors—*i. e.*, finds motor expression—it may differ greatly both in amount and character from that originally impinging upon the receptors. A very small stimulus may liberate a large amount of energy. Each neurone is a storehouse of energy which needs but the transmitted tap of the impact to release it. Evidently a series of neurones in relation with a receptor will intensify the impressions impinging upon the latter. Such an arrangement is especially evident in the olfactory lobe and doubtless accounts for the recognition by the organism of impacts so excessively minute as are those which impinge upon the olfactory receptors. Ramón y Cajal has in this connection

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employed the expression "avalanche conduction." Doubtless a similar truth obtains in regard to the intercalary neurones next in series, *i. e.*, those concerned primarily in the central transmission of the impact, and also and finally, in regard to those in relation with the effectors.

That the impact in its course of transmission through the various neurones—avalanche conduction or other—undergoes, in addition, conversions in character, is modified, transformed into different equivalents is probably equally true; but the discussion of this interesting question is deferred for the present. One truth, however, remains apparent, and that is that the 10,000 million intercalary neurones of the cortex add merely to the complexity of the response; the purely physical, automatic character of the latter remains unchanged. This automatism is as true of the higher vertebrates as it is of the lower. The reaction of the fish to the environment is clearly automatic (see p. 54), and the development of the telencephalon merely makes that automatism more complex.

A discussion which can no longer be deferred is that of consciousness. In a consideration of

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nervous phenomena, the problem of consciousness of necessity obtrudes itself, and, although in a study of the simple problems it may be ignored, it must finally be squarely faced. When we turn our attention to the protozoa and more especially to the amœba, we realize at once that a discussion whether such an organism is conscious, whether it has sensation, feeling, a sense of being, becomes futile. We have seen reason to believe (see pages 12, 14) that the reactions of the amœba to the environment, like that of the white blood-corpuscles and the other individual cells of the metazoa, are due to purely physical and chemical causes. If such structures have a sense of being, it must be one that is shared by the substance and energy of the universe generally; indeed, it must be participated in by that ultimate expression of substance and energy, the electron itself. Are we to infer that "sentiency" makes its appearance when the combination of a given number of amino-acids results in the formation of a substance that is the seat of a continuous chemical change featured by a simultaneous upbuilding and reduction (see p. 40), a continuous change that is itself a direct

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result of its reaction to its environment? or, are we to defer this conception of sentiency until special arrangements for the reception and transmission of impacts make their appearance? The difficulty increases when we approach the more complex metazoa. In the contemplation of the cœlenterates we may be content to set aside the question of "feeling," but are we justified in doing this in the case of insects with their obviously complex sense organs and central nervous aggregations? Again, are we justified in assuming that the cuttlefish in spite of his elaborate eye does not "see," has not "light sensation" of some kind or other? Assuredly it is unphilosophical to assume that the fish in spite of its enormous olfactory brain does not "smell," or being possessed of eyes and ears, that it does not "see," does not "hear." True, the impacts received by the "nose brain," the "eye brain," the "ear brain," and the "skin brain" are all transmitted into the common paths concerned in swimming, *i. e.*, in bringing about automatic approach to or withdrawal from objects in the water; yet, though the "eye brain" may glow with the sensation of light and the "ear brain" ring with the sensation of sound,

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the consciousness of the fish must be something very different from that experienced by ourselves. In what does this difference consist? Evidently it concerns the function of the telencephalon.

Let us for the time being turn our attention to the responses to impacts in the higher vertebrates. In amphibians the situation has changed but little from that in fishes; the responses are still the invariable, non-adjustable responses of a segmental brain. The same may be said of reptiles; variable or adjustable responses are negligible factors. When we turn to birds, the situation has apparently slightly changed. In addition to their very remarkable and complex automatic "instinctive" responses, there appears to be a capacity, though an exceedingly limited one, for adjustable responses. In birds the pallium—the cortex of the telencephalon—is still very rudimentary, and if the bird does any "thinking" he must do it with his thalamus and striatum. That he does very little is quite evident from the behavior of birds ordinarily; that he exceptionally does some is equally evident from the occasional behavior of certain birds, *e. g.*, the parrot. Further, it is

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exceedingly probable, as we shall see later on, that the complex instincts of birds, as well as those of mammals, had their origin in adjustable responses.

It would appear that the structures of the primitive brain, the palæo-encephalon, the segmental brain, as we term it, is of such a character as to permit of adjustable responses in only a limited degree. However, that such adjustable responses did take place in it originally and still do take place in it in birds and perhaps in lower forms, though in very small measure, is exceedingly probable. In mammals, however, the function of the segmental brain, like that of the spinal cord, is limited to non-adjustable responses. Like the spinal cord, the segmental brain has been reduced to a fixed mechanism. Such capacity for variable or adjustable responses as it may have originally possessed has been usurped by the telencephalon.

Whatever may be the state of consciousness in vertebrates other than mammals, it is quite certain that in the latter fixed responses play no rôle in consciousness; this is true of the responses in the spinal cord, and it is doubtless equally true of the responses in the segmental

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brain. Here again the telencephalon has played the rôle of usurper, for the function of consciousness, as *we* know it, is limited to the telencephalon.

When we now turn our attention to this function of the telencephalon, the following interesting facts and inferences present themselves. To begin, various acts themselves the outward expression—the effector result—of the intercalary function of the telencephalon, and which when first performed are attended by consciousness, may lose this quality when frequently repeated. Acts the performance of which is at first accompanied by a conscious effort, may by frequent repetition become largely and in some instances wholly "automatic," *i. e.*, may finally be unattended by consciousness either in whole or in part. Many of the acts acquired in early life—the use of utensils in eating, the adjustments of clothing, the movements of writing, the movements concerned in playing a musical instrument—are all acts usually at first performed slowly and with difficulty, but later with increasing ease until consciousness no longer enters into them. The same movements frequently repeated necessitate the

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constant repetition of the same association—the same combination—among the neurones, and sooner or later the movements acquire all the character of *fixed* responses.

The first inference that is justified is that consciousness disappears in proportion as fixation is established. Fixation of response means the disappearance of consciousness. This inference leads to another no less interesting, an inference that follows as a corrollary, namely, that consciousness is present only in the "adjustable" responses; that is, only in those responses which are attended by a changing, an actively varying relationship among the neurones. An impact transmitted from the cord and segmental brain into the telencephalon brings about definite changes in the synaptic relations of the neurones to which the impact is first transmitted. Thence the impact is transmitted to other intercalary neurones, indeed, to many series of the latter in the manner already indicated. The transmission of the impact, subject to reinforcement, may continue until motor centers—*i. e.*, until neurones in relation with effector (motor) neurones of the segmental brain or cord—are reached, when an

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outward or motor expression results; or the transmission may continue to diffuse variously through the cortex without a so-called motor area being involved. Whatever the course of the transmission, it is inevitable that the neurones concerned are involved in sequence. The axone-terminals of the first neurone approach and are approached by the dendrites of the second (see p. 71). The second neurone effects a like synaptic approach with the third, the third with the fourth, and so on. It follows that just as soon as an impact has been transmitted by a neurone—*i. e.*, just as soon as it has completed its discharge (see p. 81)—its axone terminals and the dendrites of the receiving cell are again retracted, *i. e.*, the synaptic relationship is broken and the neurone is again at rest. It is, I believe, a legitimate inference that a neurone at rest can have no relation with consciousness; a neurone at rest, so to speak, is unconscious. It follows, therefore, that consciousness is only present in the neurones that are actively concerned in transmission. Consciousness is itself a phenomenon of cortical transmission.

Let us at this point consider some of the ele-

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mental facts of consciousness as they reveal themselves to our individual experience. Whatever consciousness may be, it is something that is constantly changing. A sensation, a perception, a thought is experienced. A sensation persists as long as the impacts that give rise to it continue; a perception as long as the object perceived throws its impacts upon the receptors; a thought resolves itself into a train of sequences. Each individual instant of time, however, whether it is concerned in a momentary sensation derived from a single impact or whether the sensation be made up of many succeeding instants of impacts, becomes past history the moment it is experienced; it immediately enters the past. The same statement applies, of course, to a perception, to a thought; in fact, to any mental process. While consciousness is constantly changing from the immediate present to the immediate past, it is of necessity also constantly passing into the immediate future. Bergson[1] expresses the same facts as follows: "For consciousness there is no present, if the present be a mathematical instant. An in-

[1] Bergson, Mind Energy, transl. by H. Wilson Carr, Henry Holt & Co., New York, 1920, p. 8.

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stant is the purely theoretical limit which separates the past from the future. It may, in the strict sense, be conceived, it is never perceived. When we think we have seized hold of it, it is already far away. What we actually perceive is a certain span of duration composed of two parts—our immediate past and our imminent future."[1]

Surely these elemental facts are in accord with the principles governing transmission through the cortical neurones. This transmission is a progressive, continuous thing; receding from the point of entrance of the impact and at the same time continuously advancing. In considering transmission, however, it is important to bear in mind that in addition to the mere fact of transmission there is the further fact of the release of energy (see p. 81), a release in which each neurone successively takes part. As a result, an impact, thus continuously reinforced, becomes widely diffused. This diffusion, however, does not take place indifferently in all directions, but in accordance with definite principles. To begin with, it is obvious

[1] Thus far only is the writer in accord with Bergson's interpretation of consciousness. From this point on Bergson enters a maze of mysticism.

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that transmission follows the direction of least resistance. Evidently the latter will be in the course of the most frequently travelled paths, those paths in which the amœboid approach of axone terminals and dendrites has been most frequently established, or, to phrase it in other words, in which "synaptic resistance" has been most frequently overcome. Further, it is probable that the transmissions, other things equal, at first followed the most direct routes to the gateways of exit; the demands for adjustment of the responses to the environment were in the primitive mammalian forms doubtless relatively simple; as they are to this day in moles and rabbits, insectivora, rodents, and the like. However, the organism in response to the increasing demands made upon it by the environment, reacted by increasing its power of adaptation; it underwent, as we say, evolution.

The telencephalon grew, its neurones became more numerous, and its power of adjusting to the environment the responses it transmitted was correspondingly increased. Numerous "association tracts," great and small, gradually made their appearance, so that every part of the cortex became connected with every other

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part (see p. 61). Notwithstanding this increasing complexity and increased power of adjustment, notwithstanding the great facility for intercommunication, an impact entering the telencephalon is not diffused universally throughout the entire cortex. Doubtless dependent upon the nature of the impact—the exciting cause—and the special environment in which the organism happens to be placed, as well as upon other factors already considered (see p. 79), the transmission pursues a course more or less defined. The transmission is not, however, entirely limited to this course, for the neurones successively involved doubtless discharge their energy not only into those in the direct pathway of the transmission but also into neighboring neurones not directly concerned. There is, so to speak, a lateral transmission, but one of less dynamic power, and which finally dies out within a variable range of the primary activity. Consciousness follows the main train, but also includes a limited and fading field to either side —to all sides, one might say. In a sense, consciousness is analogous to the visual field with its sharply defined central vision and its gradually fading peripheral areas. The "field of con-

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sciousness" becomes less and less distinct as the main train of activity—perception, thought, emissive impulse—is departed from. Gradually it fades into the subliminal, the subconscious, the unconscious.

Again, the "train of activity" is continuous, unbroken, during the waking period. Further, the inpour of impacts is incessant, and a given "train" may be reinforced, deflected, or modified in various ways. Cessation of the "train of activity" means, of course, cessation of the synaptic transmission, a discontinuance of the "amœboid approach" of axone terminals and dendrites. Such a discontinuance means unconsciousness and, physiologically, sleep. In one of my papers,[1] read in 1897, I expressed myself as follows: "Evidently the neurones when functionally active must be in relation with each other. Their processes must be either in contact or nearly so. Evidently this condition is a prerequisite of consciousness. Now what happens when the nerve-cells are exhausted by fatigue, when their volume and their cell contents have been diminished, as we have

[1] Dercum, Application of the Theory of the Movement of the Neuron, Univ. Med. Magazine, April, 1897. See also C. L. Dana, J. A. M. A., April 24, 1920, p. 1141.

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every reason to infer is the case, from the experiments of Hodge? Evidently their processes become retracted and they are no longer in relation with each other. The neurone isolated from the rest by retraction must be without function. General retraction of neurones must mean absence of function, must mean unconsciousness, must mean sleep. In other words, in sleep the neurones have their processes retracted; in consciousness their processes are extended."[1]

Let us turn our attention to some of the other considerations that present themselves. Evidently the extent of the field of consciousness must depend upon the number of neurones called into activity, and this, in turn, must depend upon the impacts received, upon the number, intensity, and character of the latter. Further, it is the summation of the activities of all the neurones aroused at a given time which constitutes at that time the conscious individuality. The latter must, therefore, be regarded as multiple, as made up of many in-

[1] Lugaro's suggestion that during sleep there is a general diffuse extension of all nervous processes instead of a retraction would substitute activity for rest, and is, so it would appear, dynamically inconsistent with arrest of function.

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tegers, and of varying from time to time both in extent and character. The group activity, the united activity of many neurones probably gives rise to a community of consciousness, a sense of self as something distinct from the outside world. A discussion of the degree with which man shares this property with other animals would be nugatory. Its possession, however, by the latter to any extent must depend upon the presence of "variable," that is, "adjustable" responses. Without these a sense of self would obviously be impossible. Further, this "community of consciousness" must necessarily vary in extent from time to time within physiological limits; that it varies greatly in pathological conditions we will see later on.

The community of action of the cortical neurones must inevitably give rise to the function of memory. To make my meaning clear let me use the following illustration: A sequence of sound vibrations impinges upon the auditory receptors and in due course the impacts are transmitted to the "auditory center" in the temporal lobe of the cerebrum. Here the neurones assume relations with each other corresponding to the impacts received, the character,

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intensity, and other qualities of the latter; the impacts are also transmitted to neighboring and possibly distant areas. If a similar series of impacts has been transmitted by the neurones before, similar or the same combinations will be re-formed, and as a corollary there will follow a recognition by the neurones concerned in the communal relation of consciousness as something experienced before. That memory is a purely dynamic function there can, I think, be no question. The capacity for memory must depend upon the facility among the neurones for re-forming old combinations, and this facility must be increased by repetition. In a sense memory is the expression of the same tendency to fixation of neurone combinations as has given rise to the fixed relationships in the palæoencephalon. Perhaps some of the "instincts" and "race memories" have their basis in combinations of such frequent recurrence in the ancestry that they have acquired all the potentiality of inherited structure.

One of the most instructive phenomena illustrating the dynamic character of memory is that presented by memory temporarily delayed. It is a matter of common experience that

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a name which cannot at once be recalled appears in consciousness after the lapse of a fraction of a second or, indeed, at times after the lapse of many seconds, and at a time when the train of thought is already occupying another channel. It would seem that the impact leading to the memory recall had set in motion a group of neurones along paths only occasionally used or long unused, or along paths subject for the time being to synaptic resistance. The significant facts are that *time* is required for the act, and that the presentation of the name occurs *automatically*. Another significant illustration of the dynamic quality of memory is offered by the abnormal memory occasionally observed in certain defective children, the so-called "idiot savants." The latter may be able to give citations at great length of matter which they have heard only once and of the meaning of which they have no comprehension; not infrequently such citations are in foreign languages, of which the child is likewise ignorant. Such abnormal memories suggest a pathological tendency to fixation of the combinations; perhaps a disease of the synapses. Further, it is not improbable that in these children the tendency to fixation

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of the cortical responses is directly related to their idiocy. It would appear that a certain plasticity, release, and freedom of combination are essential to normal function.

Referring again to instincts, it is not improbable that some instincts are inherited modes of reaction to the environment that had their origin in responses which early in the phylogeny of the race were adjustable and which, owing to constant repetition, became fixed and relegated to the subconscious field. However, other phenomena apparently instinctive are doubtless due to the mere physical reaction of the organism to the environment as pointed out by Jacques Loeb.[1] In these reactions, likewise, the responses being fixed, they play no rôle, or at most only an indirect rôle in consciousness.

In our discussion of the transmission of impacts through the telencephalon, and especially in our discussion of memory, we have already laid the foundation for the explanation of various detailed mental phenomena such as perception, apperception, association, as expressed

[1] Jacques Loeb, Forced Movements, Tropisms, and Animal Conduct, Lippincott & Co., Philadelphia, 1918.

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in the train of thought, and the transmission of the impact through the avenues of exit to the effectors. In the act of perception the neurones of the cortex which are the recipients of a given series of impacts form combinations among themselves corresponding to the impacts received. The transmission, of course, does not cease here, but continues, as already indicated, by association, intracortical and subcortical, many neurones being called into activity. The combinations successively formed are some of them new, others are combinations which are the same as or similar to combinations formed upon previous occasions. The result is that the incoming combinations resulting from the act of perception assume relations in part to past combinations and in part to combinations wholly or partly new. In other words, it is the function of the common or community consciousness of the neurones concerned in this activity to collocate the impression received. It is this which constitutes the act of apperception. The train of thought automatically follows. The very act of collocation constitutes the train of thought. It *is* thought, no matter how diversified or complex the transmission may

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become. If it finally eventuates in a discharge through an emissive gateway, its further progress to the effectors is, of course, outside the field of consciousness.

It is evident, let us resume, that the neurones of the telencephalon are roused into action by the impacts transmitted to them from the segmental brain. As a result, the neurones involved in a given transmission extend their processes and enter into synaptic relations with other neurones, into which they also discharge. It is the active neurones alone, as already pointed out, which are concerned in consciousness. Those which are quiescent are those into which transmission has not taken place, and consequently cannot manifest consciousness. In contrast with the field of consciousness, they therefore occupy the unconscious field. It is further evident that in the progress of a transmission through the cortex, neurones previously quiescent and therefore in the unconscious field are brought into action and now become part of the conscious field, and at the same time other neurones through which transmission has been completed again become quiescent and lapse into the unconscious field. In other words, the

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conscious and unconscious fields are constantly changing; that which at one moment is conscious field at the next moment is unconscious field, and vice versa.

Again, when a transmission passes through a group of neurones, the latter react by forming combinations among themselves corresponding to the impacts received (see p. 76). A repetition of the same or similar impacts means the re-formation of the same or similar combinations (see p. 80). This implies the establishment of pathways of least resistance, and it would seem that a single transmission of an impact is sufficient to establish such a pathway. In other words, the passage of transmissions establishes "associations" among the neurones. These are manifest only when the neurones are active, and are merely potential when the neurones are quiescent. It would appear that when the latter are stimulated by a transmission, previous combinations are automatically reproduced. In this lies, I believe, the explanation of the physiology of the unconscious field.[1] The latter is a vast storehouse of

[1] I do not like the expression "unconscious mind"; the words are self-contradictory.

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past experiences. These are represented not by gross changes of structure, but merely by potential possibilities. Whether certain combinations—associations—are re-formed depends entirely upon whether the neurones concerned are reached by a given transmission.

Further, it is, I believe, a legitimate inference that the number of neurones in action at a given time is an exceedingly small part of the sum total of the neurones of the cortex. It is very probable that the number concerned in the field of consciousness—in the train of transmission, in the train of thought—is relatively insignificant when compared with the ten thousand millions of the total. Finally, when we consider the number and complexity of both the axone terminals and of the dendrites, and the fact that every part of the cortex is in relation with every other part, we can perhaps form a faint conception of the practically limitless possibilities of association. Not only may the latter consist of combinations representing impacts the same as or similar to impacts already transmitted but also of combinations entirely new. The organism is constantly exposed to new and changing relations to the environment,

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and to these demands the organism reacts by a constant readjustment in its responses. The individual from infancy on, from his very earliest experiences, throughout his training and education, up to the complex experiences of adult life, is constantly making fresh adjustments, *i. e.*, new combinations, new associations among his neurones.

There can be no doubt that the power of the continued making of new combinations differs in individuals. In the larger number the combinations that are formed resemble those that are formed by other individuals under the same circumstances, *i. e.*, who are exposed to the same impacts. In others, a relatively small number, the combinations differ in a degree sometimes slightly, sometimes widely, from those formed by the average individual. It is the novel character of the associations formed among the neurones that constitutes "originality." If the novelty of the association be very pronounced, it gives rise to "imagination"; originality and imagination are close kin.

The field of consciousness—*i. e.*, the train of transmission—is, of course, of relatively greater dynamic power than the unconscious field into

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the neurones of which it successively discharges. Whether into the field of activity itself fresh impacts, impacts derived from other sources than that which originally gave rise to the transmission, find entrance, is purely a question of dynamics. If the dynamic level of the active field be relatively high, the ingress of disturbing impacts is excluded and the original transmission pursues its way undisturbed and untrammeled. In such case it is open only to impacts derived from the same source that gave rise to it and which continually reinforce it. It is this which constitutes "attention." Lack of attention, the inability for sustained attention, is due to the ingress of interfering transmissions and, other things equal, is expressive of a lower dynamic level—*i. e.*, of weakness.

Similarly, the relatively high dynamic level of the conscious field especially when joined with novel associations gives rise to "initiative," to the outward expression, to the discharge—through the emissive gateways—of the cortical energy. Between "initiative" and "will" or "will power" there is again a close kinship. Given the exclusion of interfering transmissions as in attention, or in that higher degree of at-

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tention to which we apply the term "concentration," and given a high dynamic level of the train of transmission—the field of consciousness—"will power" is the necessary outcome. The dynamic level of the field of consciousness —*i. e.*, the output of energy—must inevitably depend upon the intensity of the metabolic processes, the chemical changes, going on in the substance of the neurones and upon the number of the neurones taking part.

To the conception of the purely automatic character of the phenomena of transmission, of the amœboid movements and the serial discharges—in short, of the physico-chemical changes which constitute the train of consciousness, we must now add another, or rather recall to our minds a quality of the neurone already in part considered. Consciousness implies "sentiency" (see p. 84) as a property of the neurone. Consciousness without this property would cease to be consciousness. Sensation is a self-evident condition of consciousness and is inseparable from it. Now we have already considered some of the fundamental reactions of living protoplasm to the incident forces of the environment, the gradual evolution of

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special receptors, and the evolution of special portions of the primitive brain, the "segmental brain," into which the impacts are transmitted. These are differentiated in the fish into an "olfactory brain," an "eye brain," an "ear brain," a "skin brain" (see p. 50). The inference becomes unavoidable that these structures respectively experience the sensations of odor, light, sound, and touch (see p. 84). The question now arises what rôle does the telencephalon, the great usurper, play in this respect. From the evidence of structure, only one inference is possible, namely, that the impacts from the various receptors are transmitted to the cortex. If transmitted to the cortex they must be still farther transmitted, diffused, according to the principles indicated in the preceding pages. We have no reason to infer that the mode of motion of the impact is thereby changed, *i. e.*, in passing from the neurones of the segmental brain to those of the telencephalon or in the passage from the gateway of ingress to other areas of the cortex; and, if this be true, it can only be that sound, for instance, is experienced in every neurone reached by the transmission; or light, or smell, or touch, as the case may be. When,

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as is frequently the case, transmissions are received simultaneously from several special sense receptors, the impacts do not interfere with each other. Both the sound and the object that produces it may be perceived at the same time; one through the receptors, for hearing and the other through the receptors for vision. Corresponding neurone associations, as already indicated, are formed. So it is doubtless when the impacts are received from many receptors; for instance, of sound, sight, smell, taste, touch, all at the same time. This would seem to be a necessary result of the elemental reactions of protoplasm to the incident forces of the environment; a matter which we have already fully discussed (see p. 33 et seq.).

It would appear to be a logical conclusion that, in a sense, the entire cortex sees, hears, smells, tastes, and feels wherever it is traversed by the transmission. The so-called cortical centers appear merely to be avenues of ingress and egress to the general cortex, as already pointed out. To be sure, the cortex varies in its different parts in its detailed structure and presents peculiarities in both the receptive and emissive areas; *e. g.*, in the "visual area" in the

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occipital lobe and in the centers of the "motor area." Here peculiarities of structure are found whose function is that apparently of the reinforcement of transmissions. However, the neurone of the telencephalon appears to have retained along with its lack of fixation, along with its amœboid movement, the general elemental qualities inherent in the primitive neuroblast, elemental qualities which are shared by the entire cortex. Other things equal, this lack of fixation of function, like the absence of fixation of the neurone itself, appears to have been and still is a necessary condition of its continued evolution. Differentiation and specialization, therefore, while it has taken place in the cortex, has not interfered with the continued adaptation and adjustment of responses and the continued forming of new associations or combinations. Sensations are only experienced by the neurones taking part in the transmission, and these sensations doubtless depend for their kind upon the special receptors by which the impacts are received. The kinds of impact are much more numerous than would be implied by a consideration merely of the senses of smell, taste, vision, hearing, and touch. There are,

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first, the subdivisions of vision; namely, the perception of moving objects, of form, and color; secondly, the addition to the receptors for hearing of those for equilibrium and sense of position, and, lastly, the addition to touch of the senses of pressure, temperature, and pain.

In addition to the receptors which receive impacts from sources external to the body, there are receptors which receive impacts arising within the body. Sherrington, as already stated, has termed the first "exteroceptors" and the second "interoceptors." Besides these there is a third group of receptors situated in muscles, bones, and joints, which give information as to the state of these structures when the parts concerned are moved. These Sherrington has termed "proprioceptors."

It is quite clear, let us repeat, that the specific sensations aroused are dependent upon specific impacts received. In addition to these, however, the neurone when active—*i. e.*, when taking part in the train of consciousness—also experiences other sensations, namely, those comprised by pleasure, pain, the emotions or affects. These may be slight, moderate, or intense in degree. In their production the in-

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ternal secretions, the hormones, and the sympathetic and autonomic nervous systems play an important rôle; at times the active cause is to be sought in toxic substances bred within the body or taken in from without. There is every reason to believe that the impacts which give rise to sensations of pleasure and pain affect primarily neurones in the segmental brain, the palæoencephalon, namely, "cortical dependencies" in the thalamus (see p. 58). That they are transmitted to the telencephalon and that they play a role in consciousness and profoundly influence the train of neurone activity in the cortex goes without saying. The hormones or toxins probably act upon the sympathetic nervous system, upon the neurones of the thalamus, and the neurones of the cortex; it is probable that in the latter, in many instances, they act upon the synapses. If this be the case, transmission must be profoundly influenced. On the one hand, it may be greatly retarded or inhibited, as in depressed mental states, *e. g.*, in melancholia, in which we have probably to do with a toxic hormone as the cause both of the mental pain and the retardation of the mental processes. How much the

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retardation of itself may serve as a cause of mental pain is an interesting question; probably it also plays a rôle. Interference with the synapses doubtless retards the "discharge of energy" to the neurones next in succession, and this "blocking" or retardation of function may itself be a cause of pain in the neurone.

In the opposite condition, that of mania, the normal resistance offered by the synapses is greatly lessened; there is a general release of inhibition and it is not improbable that the resulting increase of discharge, the heightening of function, is directly related to the "expansion," the pleasurable, aggressive, mental attitude so characteristic of this condition.

Speculation as to the details possible or probable in the play of the emotions may lead us astray, but perhaps a few thoughts as to some of the fundamental physical principles which may underlie such elementary phenomena as pleasure and pain may not be amiss. For example, certain sequences and certain combinations of sound give us the pleasurable sensation which we term "music." The thought suggests itself that the impacts transmitted to the neurones, *i. e.*, the vibrations, are of such a

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character as to be taken up by the molecules of the neurones without causing a disruption of their structure, or at most, only a minimal consumption of substance. It is probable that sounds which are harsh, discordant, cacaphonous, are painful because they actually cause destruction of the neurone molecule. Consumption of substance accompanies all discharge of function (see p. 81), but impacts that result in motions that are possible to or in harmony with the structure of the neurone molecule are probably accompanied by pleasurable sensations. Possibly in some such thought as this is to be found the explanation of the pleasure and pain experienced through the other senses. May we perhaps be permitted to extend this conception to pleasurable and painful emotions? How markedly the latter are at times attended by the evidences of physical exhaustion—*i. e.*, consumption of substance—need hardly be pointed out. The relation between general nutrition and a sense of well-being is well known. Many factors, however, enter into the problem, and a detailed consideration of the affective qualities of mind would lead us too far afield. Suffice it to say

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that the elemental qualities of pain and pleasure were in primitive forms doubtless related, on the one hand, to injurious or destructive influences, and, on the other, to the intake of food and other physical compliance with the needs of the organism. Later, in the course of evolution, there ensued specializations and differentiations of impressions, impressions derived both from the external world and from the body of the organism itself. At the same time special receptors, both extero- and interoceptors, together with special neurone pathways were evolved. Later, with the increasing development of the telencephalon, there came a further differentiation in the impressions and their corresponding neurone reactions and an increase in the adjustment of the response, *i. e.*, in the behavior of the individual. Into the final result there may have entered, on the one hand, physical pain or physical pleasure; or on the other, joy, satisfaction, sorrow, disappointment; or, it may be, a refined feeling of altruism or perhaps of an almost impersonal regret.

In the preceding pages the writer has endeavored to apply purely physical conceptions

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to the interpretation of mind. The view that mental phenomena are in their essence physical finds confirmation in the facts of so-called psychophysics. These embrace especially the results of the experimental study of the time relations of mental processes and of the phenomena underlying the sense impressions. While a consideration of these phenomena in detail would here be out of place, let it suffice to say that as regards the first, namely, the time relations or reactions—the time required for the response to sense impressions—they are significant in the fact, first, that *any time at all* is required, and secondly, that this time is in distinct relation to the complexity of the experiment and the condition of the individual; *i. e.*, whether the latter be in good health, whether he be fatigued, or perhaps under the influence of some stimulant or drug, or the subject of disease. Clearly, all these factors are physical in their nature. In this connection the interesting facts of the "personal equation" in the making of astronomical and other scientific time observations also present themselves. We are forcibly reminded, too, of the part which the synapses play in the

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delay of responses; though it goes without saying that some time must necessarily also be consumed in the transmission through the dendrites, bodies, and axones of the neurones.

It is, however, in the field of the experimental studies upon sense impressions that the most significant and most convincing results have been achieved. It was found, for instance, that a sensation aroused by a given impression having been noted, an increase in that sensation can only be brought about by a proportionate increase in the intensity of the impression. It was found, further, that in order to bring about such an increase of sensation, the increase of intensity of the impression made upon the receptors must be in a geometric ratio to the increase of sensations; that is, the intensity of the sensation increases in an arithmetic progression, the intensity of the stimulus in a geometric proportion. Thus, a man capable of distinguishing between the weight of 16 ounces and 17 ounces, cannot distinguish between 32 and 33 ounces, but only between 32 and 34 ounces. Again, a man capable of distinguishing between 20 and 21 grammes, testing a weight of 250 grammes

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cannot tell when an increase is reached until 12.5 grammes are added. If he looks at a light of 10 candle-power he cannot become conscious of an increase in the intensity of the light until 2 candle-power are added; if he looks at a 60 candle-power flame 12 candle-power must be added; if it is a 2000 candle-power light, 400 candle-power must be added.[1] Similar facts obtain as regards the appreciation of intensity of sounds and as regards intensities of pressure. As regards the senses of taste and smell, of temperature, and the various somatic and visceral sensations, the conditions are such as to preclude very satisfactory experimentation. However, in regard to the senses in which such studies are possible, there can be no doubt as to the facts. A physiologist of a past generation, Weber of Leipzig, discovered these facts more especially in regard to auditory and cutaneous sensations, and they constitute what is today known as Weber's law. Many studies have since been made and various interpretations advanced, *e. g.*, by Wundt and by Fachner, and the facts may be briefly summarized as follows: an increase of sensation

[1] Ebbinghaus, Abriss der Psychologie, 1909, pp. 66, 67.

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depends, as above stated, upon a proportionate increase of the stimulus; the increase of sensation is in arithmetic progression, that of the stimulus in geometric progression; or, to state it in other words, the sensation increases in proportion to the logarithm of the stimulus.

Clearly we have here a hint not as to the relations between physical impressions and a spiritual world, as various interpretations would lead us to believe, but a hint as to the structure of the proteins that make up the neurone and the physical laws which these proteins must obey. In a sense Weber's law is as purely physical as the one which tells us that light is inversely as the square of the distance and must be equally accepted. The facts of Weber's law, however, lead—it seems to the writer—to inferences far more fundamental and important. We have already seen that the number and character of the impacts which living protoplasm can take up is comparatively small. Only in an extremely limited degree do the changes induced in the protoplasm represent the changes—the multiplicity of forces—in the outside world. To this conception Weber's law adds another; namely, that such changes

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as are represented are only approximate; the very constitution of the protein molecules forbids an even and continuous recognition of the increasing intensity of impacts. If this is true of the recognition of so simple a quality as increase of intensity, may it not be true also of other qualities of the impacts? The thought that suggests itself is that the changes induced in living protoplasm by the impacts are, *first*, only such as the protoplasm is capable of receiving and, *secondly*, that these may and probably do in themselves correspond only imperfectly to the changes going on in the outside world. We can only be conscious of the changes in the protoplasm of our own substance, *i. e.*, the changes in the proteins of our neurones; our knowledge of the outside world is necessarily limited to these changes and must of necessity be imperfect. Further, our knowledge is purely inferential. That multiple qualities of the outside world produce no changes in the proteins of the neurones we have already seen; that other qualities induce changes which only imperfectly represent those of the outside world is, it must be conceded, equally true. What are we to say of the memory pictures and of

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the general and abstract conceptions based upon these? Of the memory pictures it may be said that they can at best represent only more or less approximately actual past responses to impacts. Of the general conceptions—*i. e.*, the composite pictures resulting from accumulated responses—it may be said that they are at best imperfect approximations to general external truths, and are liable to vary and change with additions to the impacts and corresponding fresh responses; that is, with an increasing experience. When we approach the field of abstract conceptions we clearly tread upon dubious ground. In reality, abstract conceptions represent nothing that actually exists in the outside world. At most they are artificial pegs upon which to hang the logic of our ideas. And, as regards our logic, is not this faculty dependent upon our own structure, upon the arrangement of our neurones, and upon their contained proteins and other substances? In how far is it to be trusted? Does it not at times lead us into gross absurdities? We need but recall the time-worn story of the race between the hare and the tortoise. Each interval of space existing

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between the two is divisible, and no matter how small the space may become it is still divisible; indeed, it is inconceivable that the space should become so small that it should not be still further divisible; and so it becomes *logically* impossible for the hare ever to catch the tortoise. Similar vagaries of neurone activity doubtless lie at the basis of such abstractions as the fourth, fifth, and sixth dimensions of space. As regards the fourth dimension, Einstein, after pointing out the relations of a given body to the three dimensions of space, points out that all bodies in the universe are in motion, and as it takes time for a given body to move from one point to another, time is the fourth "dimension" of space. To my way of thinking, it would be better to say that time is an essential factor in all conceptions of spatial relations[1]; or to put the fact into simpler language, merely to say that "all space is filled with moving matter." Time and the three dimensions of space are abstract conceptions, but the conception of "dimensions" having once been admitted, it becomes logically cap-

[1] In a sense, every measurable element is a dimension, and in this sense time is a fourth dimension of space.

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able of indefinite multiplication; hence the fifth, sixth, and further dimensions of space. Is there not here an analogy to the logic of the race between the hare and the tortoise? In one instance there is indefinite division, in the other, indefinite multiplication.

Evidently the logical process must be constantly curbed, held in check, inhibited by the correcting influence of the impressions received from the external world. We *know* that the hare *does* pass the tortoise, and we know also, no matter what our mathematical friends may say, that the multiplication of the "dimensions" is in crass contradiction with the orientation of our senses, *i. e.*, with human experience.

A biological interpretation of mind leads, I believe, to a more wholesome, a saner conception of its functions and limitations. It may be noted that in this essay, up to the present moment, the word "psyche" or its equivalents and derivatives have not been employed. At the very outset the necessity was pointed out of laying aside preconceived ideas, prejudices,

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and beliefs. To introduce at this point an "immaterial" something, of unknown and unascertainable character, to insert such a something into the problem renders the latter hopelessly unintelligible. Further, when we pause to consider the intrinsic meaning of the word psyche and its equivalents, most suggestive inferences present themselves. The Greek word ψυχή has the primitive meaning of the *breath:* indeed, given the Greek pronunciation, the sound is literally that of the escaping breath. In primitive times the "breath" was looked upon as the vital principle, and its final escape in the act of dying as the departure of that vital principle. The ψυχή naturally and subconsciously represented the idea of an "immaterial" constituent of our beings. A similar interpretation is applicable to the Latin word *spiritus*, the primitive meaning of which is likewise air, exhalation, breath, and its root still forms the integral parts of the words respiration, inspiration, expiration. The Latin word "mens" is free from such objections, for it literally means the mind, the understanding, the intellect, and to me it has seemed much more fitting to employ its de-

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rivatives than those derived from ψυχή or from spiritus.

In conclusion, I may perhaps be permitted to say that there is nothing in the position here assumed which should shock or give pain to any one. The study of the recondite problems of human existence is in a sense a study that is imperative and should be pushed to its ultimate conclusions. Our knowledge of the constitution of the universe as revealed by the marvelous truths of radio-activity, of the structure of the atom, and by the field opened up by Einstein's discoveries and theories, is but an expression of this tendency; surely it should not be denied us in the study of mind. The modern study of the atom reveals it to be but an expression of energy, indestructible, persistent, unknowable. Does not this cause the difference between the old conceptions of "material" and "immaterial" to disappear? Does it not make unnecessary—as it is impossible—a "dual" conception of the universe? Finally, we should remember, that as regards religious conceptions, each human being is entitled to hold such faith as he chooses, and, further, that it is the necessary

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and essential attribute of religious faith that it should be incapable of scientific proof. A religious faith that would be capable of mathematical demonstration would be no faith at all.

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ADDENDUM ON THE PATHOLOGICAL PHYSIOLOGY OF MIND

An application of the facts and deductions embraced by the within essay to mental disease is both obvious and interesting, and the writer has thought it fit to add the following paragraphs.

In the body of the essay, the writer has pointed out how the retraction of the dendrites and axones of the neurones explains the palsies and anæsthesias of hysteria. In other words, the functional break is referred to the synapses. A similar explanation applies to the palsies and anæsthesias of hypnosis which, as Gilles de la Tourette long ago pointed out, is merely hysteria artificially evoked. All of the phenomena of these states are undeniably mental, *i. e.*, cortical in their origin. This is true alike of the motor, sensory, visceral, as well as the more strictly mental reactions. In hypnosis, for instance, a partial sleep is induced in which the admission of impacts from the various

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receptors is inhibited save from those of the sense of hearing. The instructions, *i. e.*, the suggestions, are made orally by the operator[1]; all other avenues of contact with the outside world are for the time being closed. The train of neurone activity, therefore, which is set in motion by the suggestions of the operator pursues its way unchecked, uncorrected, for the impressions ordinarily received through vision or the other senses cannot gain access to the train of neurone activity, the field of consciousness. That under such circumstances the subject should prove to be exceedingly susceptible to the suggestions of the operator is not surprising; even when the suggestions are in crass contradiction with the situation in which the subject happens to be placed and with his previous experiences.

The patient suffering from hysteria while not in any sense asleep, as in hypnosis, yet resembles the hypnotized subject in being abnormally susceptible to suggestion. Both Charcot and Gilles de la Tourette long ago stressed this factor in their descriptions of hysteria. It was Babinski, however, who espe-

[1] Except, of course, in special instances.

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cially pointed out the fact that the symptoms have their origin in suggestions that may arise from causes within as well as from causes without the patient. Especially instructive also were the facts which Babinski presented in regard to the production of special symptoms by the medical examination itself. He pointed out, for instance, that the reason hysterical hemianæsthesia predominates on the left side of the body is because the physician, being usually right-handed, has the brush or æsthesiometer in his right hand, and, facing the patient and asking the usual questions, he naturally tests the left side of the patient's body first. thus suggesting the very anæsthesia he is trying to discover. Similar facts obtain in regard to the induction of other sensory losses and other symptoms. The fact, however, of greatest importance is that the same or similar procedures may be practised upon normal persons, but without the slightest result. In other words, the hysterical subject accepts suggestions both direct and indirect; the normal person repels them. The personality of the hysterical patient is a very vulnerable one. Hysteria is, indeed, a neuropathy of degeneracy. Its

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symptoms are always expressive of a biological inferiority, and, in keeping with this fact, it presents a large element of heredity. Charcot and his pupils regarded hysteria as always inherited; all other causes have merely the value of provocative agents. It would appear that, as in hypnosis, impacts received by other receptors than those which serve as the entering avenue of the suggestion, fail to reach or to adequately enter the train of transmission, the field of consciousness. That when the field is entered as a result of psychotherapy or other cause, or when the suggestion giving rise to the symptom ceases to be operative, the symptom disappears, is a matter of common experience. It is not my intention here to consider the mechanism of hysteria in detail, such for instance, as is illustrated by the immediate disappearance of the hysteria of litigation when the claim is settled or otherwise disposed of, or, of cases in which other "mental compensation" equally powerful occurs; for this would take us too far from our subject.

The discussion of the phenomena of hypnosis and of hysteria leads naturally to the discus-

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sion of dreams; the latter, it should be added, however, may be entirely normal manifestations. As in hypnosis and hysteria, there is in a dream a field of cortical neurones active during a period in which impacts received by the special sense and perhaps other receptors are denied access. A field of cortical activity, a "train of transmission" arising during sleep, may have its origin in one of two ways: First, transmission of impacts into the telencephalon by way of the special sense receptors being suspended during sleep, transmission can only arise from impacts received from the viscera or from the soma generally; *i. e.*, from the interoceptors or proprioceptors. Secondly, it is exceedingly probable that a train of transmission may be started by direct stimulation of the neurones by substances circulating in the blood; for example, by hormones present in unusual amount or modified in character, or by toxins resulting from overfatigue or introduced from without. The neurones, too, as a result of fatigue or other cause, may be abnormally irritable. It is exceedingly probable that toxins act primarily upon the terminals of the dendrites and end-tufts of the axones, *i. e.*, upon

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the synapses. It can readily be comprehended how in this way a train of transmission, a field of cortical activity, may arise. The train of transmission no matter how arising, being uninhibited, *i. e.*, uncorrected, by impacts received from the external world, now diffuses along pathways of least resistance; former neurone combinations are re-formed, many former ones are compounded; unusual and bizarre combinations result.

Considerations such as the above lead not unnaturally to a consideration of states of delirium and confusion. Here we have to deal with problems of infection, intoxication, and exhaustion; and doubtless with the action of toxins and poisons directly and primarily upon the synapses and secondarily upon the bodies of the neurones. Irregularly occurring, constantly changing combinations, discharges and retractions appear to feature the conditions; more active and pronounced in delirium; delayed, slower in confusion; and abolished in stupor. In keeping with this interpretation we find delirium featured by hallucinations, illusions, and unsystematized, fragmentary delusions. An hallucination is doubtless excited

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by the direct action of the toxin on the neurones of a special sense receiving area of the cortex; quite commonly it involves the auditory or the visual area. The disturbance forcing itself into the train of neurone activity already existing is naturally regarded by the latter, the "communal consciousness" (see p. 96), as something coming from without, and the noises, words, or phrases heard or the object seen are referred to the outside world. That in delirium errors of perception also occur is not surprising. An illusion—excluding, of course, errors in the receiving apparatus, the special sense organ—is due to a faulty combination of the neurones of the cortex in response to the impacts received, or to an imperfect or aberrant correlation (integration) with combinations previously formed; thus occur mistakes in the recognition of objects and persons. That the resulting state of the communal consciousness should be one of confusion more or less active according to the intensity of the disturbance is what we should under the circumstances be led to expect.

It is one of the essential features of delirious and confused states that there is an absence of fixation of any of the symptoms. The pic-

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ture is one constantly changing, constantly varying; in an active delirium the picture changes with kaleidoscopic suddenness; in confusion much more slowly; while in stupor the deadening weight of intoxication and exhaustion abolish all manifestations whatever.

In certain mental diseases fixation, on the contrary, sooner or later makes its appearance. In order that its significance may be fully appreciated a digression will be necessary.

There is a group of mental diseases which have their beginnings before the foundation of the organism is laid. The building material is imperfect, poor in quality, vitiated, so that the resulting structure crumbles and gives way under its own strains. Mental symptoms make their appearance relatively early, and this caused the early French writers, notably Morel, to speak of it as *démence précoce*, a name which Arnold Pick long after rendered into the now generally accepted term "dementia præcox." As might be expected, the number of factors which enter into the impaired heredity of the patients is exceedingly large and varied, *e. g.*, mental and nervous disease, syphilis, alcoholism, criminality, prostitution, vagabondage, eccen-

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tricity; in fact, all forms of degeneracy, misfits, and failures.

Dementia præcox is essentially an affection of endogenous deterioration. It should really be spoken of in the plural, as the insanities of adolescence, because in keeping with the many and varied hereditary factors entering into its causation, it manifests itself in many forms. Long ago two groups were isolated by Kahlbaum, which he termed respectively "hebephrenia" and "catatonia," and to these Kraepelin later added a third, "paranoid dementia." Later still Kraepelin distinguished ten different forms instead of three, but in this he has not been generally followed; and doubtless largely because, as Kraepelin himself admits, there are between the various forms so many transitional forms that they cannot be sharply delimited. For practical purposes the segregation into hebephrenia, catatonia, and paranoid dementia is quite commonly accepted. Hebephrenia is a relatively simple form, which occurs, on the whole, in the younger individuals; catatonia is distinguished more especially by the addition of certain motor phenomena and also presents slight evidences of "systematiza-

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tion" of the delusive ideas, and occurs, on the average, in somewhat older patients. Paranoid dementia is distinguished by a more pronounced systematization and occurs, on the average, in a still older group. That many transitional forms are met with need hardly be restated.[1]

Space and the objects of this Addendum do not permit of a consideration of the symptoms of dementia præcox. Suffice it to say that the known facts in our possession point clearly to an autotoxic state and exhaustion.[2] The onset of symptoms is gradual, usually bearing the character of a confusion, sometimes with varying elements of systematization and, let us repeat, of weakness and exhaustion. That a progressive deterioration and a final dementia should ensue seems quite natural; and it is this that occurs in the larger number of cases.

[1] Because of his interpretation of dementia præcox as a cleavage or fissuration of the mental functions, Bleuler invented and proposed the name "schizophrenia," which he believes to be preferable to dementia præcox. However, cleavages and fissurations of the personality are not confined to dementia præcox, but also occur in other forms of mental disease as well as in the neuroses. Both the term and the affection lack the specificity that would justify its use.

[2] Dercum, The Story of Dementia Præcox, New York Med. Jour., Aug. 12, 1916; also Clin. Manual of Mental Dis., p. 108.

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The behavior of the neurones, their synapses, and cell bodies, in confusion we have already considered. The researches of Fauser and others point among other things to the ingress into the blood of an abnormal hormone from the sex glands. Together with this we have a nerve substance inherently defective and feeble in resistance. As a natural result there is present, in addition to the confusion, a more or less marked adynamia of the field of cortical activity, the train of transmission. The level, the intensity, of the metabolic processes of the neurones is lowered. In keeping with this there is slowness of speech and poverty of thought which eventuate in mutism, in fixed positions, stereotypy, automatism, perseveration, verbigeration; or it may be stupor. The train of transmission is reduced to a shallow, a narrow, a monotonously trickling stream, which may for a time cease altogether. Now and anon, tributary currents join what is left of the main stream, but they do so irregularly, at unusual points, and at variance with the orderly sequence of neurone combinations. While the cortex is adynamic as a whole, it may happen that the field of cortical activity

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is more greatly reduced than other portions. Under normal conditions the train of transmission, as already pointed out, diffuses, discharges into other and still inactive areas. However, if the level of the active field is greatly diminished and other portions of the cortex become, as a result of the toxic causes at work, spontaneously active, and if they possess relatively greater dynamic power, the direction of the diffusion may be reversed and these new activities may flow into the less resistant field. It is not necessary to suppose that they represent "complexes" that have been "repressed," to use the language of the Freudians. They may, of course, represent a variety of things; on the one hand, "wishes" and things desired, and, on the other, things of which the patient stands in fear and dread; but not necessarily either.

We have already traced the origin of a hallucination, *e. g.*, of hearing, and how it breaks into the train of transmission and how it is naturally regarded by the already existing communal consciousness as something coming from without. In a similar manner, other groups of neurone combinations may, as a result of

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their greater dynamic level, diffuse their energy into the less active field. That phenomena of cleavages and fissurations of the personality should under these circumstances result is what might be expected, but this is no reason, as has already been pointed out, for giving to dementia præcox the specific name of schizophrenia.

Let us return now to a consideration of fixation which in certain mental diseases sooner or later makes its appearance. We have seen how in delirium and confusion there occurs an ever-changing and ever-varying combination among the neurones. Synaptic relations are continuously and irregularly made and broken. We have seen, also, that in dementia præcox, especially in the younger group, the mental picture is that of a confusion, but that in the older groups "systematization" of the delusive ideas may in some degree be present. By systematization is meant the arrangement of the ideas into logical sequence; in other words, a systematized delusion is one which has a logical structure. Now, it is the essence of an

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insane delusion that the person holding it is incapable of accepting evidence concerning it; *i. e.*, such evidence as is accepted by ordinary men or by normal minds. This can only mean that the neurone combinations concerned in the delusions are inaccessible. It is entirely justifiable to assume that we have here to deal with relations between neurones which recur with such ease and constancy as to be potentially fixed in character. Inaccessibility to conflicting trains of neurone combinations is a necessary result. Any impulse approaching the neurones concerned merely results in the reformation of the old combinations. In keeping with this we meet with another fact, and that is, that a delusion once fixed becomes permanent. This is typically illustrated by the history of the various forms of paranoia, and, indeed, in general terms, it may be stated that the appearance of systematized delusions in a given mental case is always an unfavorable omen.

The application of the physiological principles developed in the within essay to melancholia and mania has already been indicated (see p. 111). In melancholia the retardation

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may properly be ascribed to a depressing action upon the function of the synapses of a toxic hormone. Possibly to this, as well as to the general action of the toxin upon the neurone bodies, the mental suffering is to be attributed. It would seem a not illogical inference to regard the painful delusions so frequently present, as secondary outgrowths, as the explanations devised by the patient to account for his sufferings. At all events, the mental distress is the essential feature, as witness the cases of simple though severe melancholia without delusions.

In the phase of mania, as already pointed out, the resistance of the synapses is greatly diminished; there is a general release of inhibition. It would seem that as a result of the toxic hormone or other cause at work, the neurones evolve and discharge their energy with unusual ease and that the latter flows with lessened resistance along the cell processes. The patient is expansive, aggressive, boisterous, boastful, buoyant. He talks incessantly and with great rapidity; he rapidly embraces the objects and persons in a room in the scope of his perceptions, but fastens his attention upon nothing. Illusions of objects and persons, due in part

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to the fragmentary and imperfect character of the perceptions and in part to abnormal associations, are a natural consequence. The associations are usually striking, unexpected; often they consist of meaningless rhymes, similarly sounding words or syllables, puns, mere assonances. There is an enormous increase in the flow of ideas; but the latter are evanescent, fugacious, unessential; what we hear is richer in words than in ideas.

The expansion and the enormously increased association of mania is in keeping with heightened nervous outflow, the increased energy discharged by the neurones. Along with this are the motor excitement and the unusual, the bizarre, the pathological character of the associations. We can understand, perhaps, why the nervous overflow should pass along unaccustomed channels; perhaps, also, why the associations lose their intimate, elaborate, and finer qualities; why they should become coarse or relatively so. Normal acts require time, and probably in proportion to the amount of detail. In mania the discharges appear to be diffused *en masse* and probably along the larger pathways in which the least

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resistance is encountered. Possibly there is here an explanation of the coarseness and superficiality of the associations. Finally, it is probable that fatigue early impairs the synapses upon which the finer adjustments depend, so that as the case progresses coarse and flaring associations alone are present.

A concluding paragraph upon the mental disturbances, the dementias, which ensue upon the gross destructive action of poisons, such as lead and alcohol, and upon the destruction of the neurones by the ravages of the Spirochæta pallida and other agents, hardly seems necessary. The action of these is obvious and the details do not here concern us.

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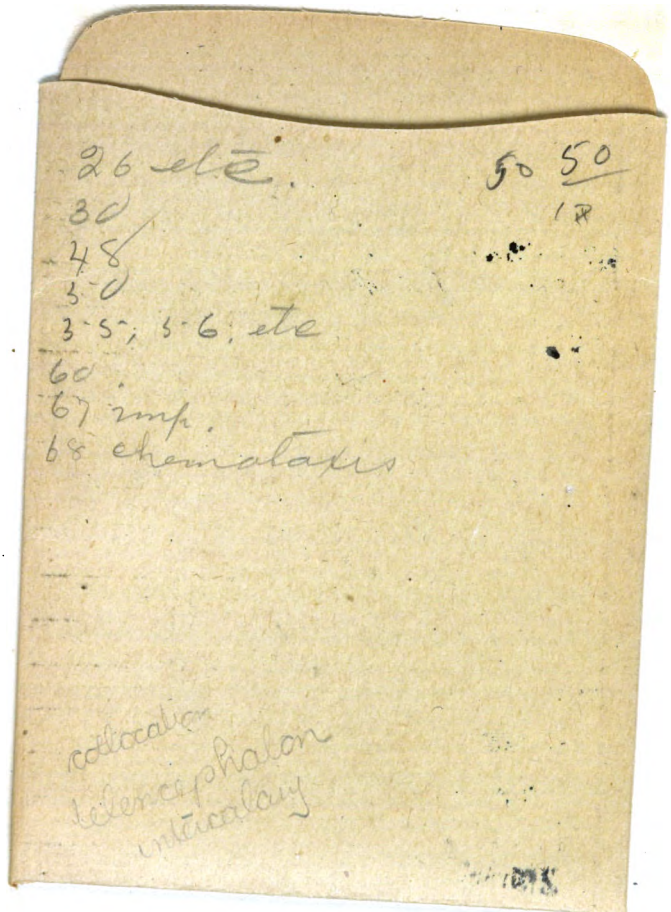
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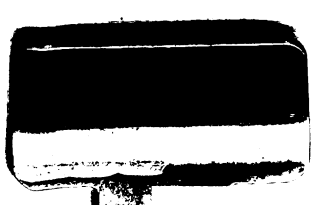
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